NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

FORECASTING MAINTENANCE SHORTCOMINGS OF A PLANNED EQUIPMENT DENSITY LISTING IN SUPPORT OF EXPEDITIONARY MISSIONS

by

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June 2017

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.			
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2017	**3. REPORT TYPE AND DATES COVERED** Master's thesis	
4. TITLE AND SUBTITLE FORECASTING MAINTENANCE SHORTCOMINGS OF A PLANNED EQUIPMENT DENSITY LISTING IN SUPPORT OF EXPEDITIONARY MISSIONS			**5. FUNDING NUMBERS**
6. AUTHOR(S) Oludare A. Adeniji			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number ____N/A____.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.			**12b. DISTRIBUTION CODE**

13. ABSTRACT (maximum 200 words)

The Marine Expeditionary Unit (MEU) is the U.S. Marine Corps' premiere forward-deployed force that possesses the capability to provide self-sustainment for a minimum of 15 days. This thesis takes a close look at how the U.S. Marine Corps supports expeditionary deployments. Expeditionary logistics has long been a challenge within the Department of Defense. This study focuses on improving the level of organic support available to deployed units. More importantly, it examines the methodology used to build the class IX block embarked on ship prior to deployment. The class IX block is defined as a repository of maintenance items available on-ship throughout the deployment without external support.

The sample data used in this research is an accurate representation of an Equipment Density Listing (EDL) used in support of a deploying MEU. The goal of this thesis is to provide results that can be compared to historical data to evaluate model and simulation outputs.

This thesis provides recommendations on improving the methodology implemented in building class IX blocks for future expeditionary deployments, including the need to gather and retain more data to better understand uncertainties in parts usage. Lastly, recommendations are given for future studies in support of MEU equipment sustainment.

14. SUBJECT TERMS class IX block, simulation, readiness, Marine Expeditionary Unit, MEU, Bayesian statistics			**15. NUMBER OF PAGES** 115
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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FORECASTING MAINTENANCE SHORTCOMINGS OF A PLANNED EQUIPMENT DENSITY LISTING IN SUPPORT OF EXPEDITIONARY MISSIONS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

ARG	Amphibious Readiness Groups
BX	Box
COA	Course of Action
CSV	Comma Separated Values
DOE	Design of Experiments
EA	Each
EBO	Expected Backorder
EDL	Equipment Density Listing
FLIS	Federal Logistics Information System
FSC	Federal Supply Class
GCSS-MC	Global Combat Support System - Marine Corps
GENPAC	Readiness Based Sparing and Generator Package
LPV	Marine Corps Logistics Vision and Strategy Branch
MARREDU	Marginal Reduction
M&S	Modeling and Simulation
MAGTF	Marine Air Ground Task Force
MARLOGCOM	Marine Corps Logistics Command
MEF	Marine Expeditionary Force
MET	Mission-Essential Task
MEU	Marine Expeditionary Unit
MOE	Measure of Effectiveness
NIIN	National Item Identification Number
PMF	Probability Mass Function
OMFTS	Operational Maneuver from the Sea
QTY	Quantity
RNSN	National Stock Number
SAC	Stores Account Code
SC	Signal Command
TLCM-AT	The Total Life Cycle Management Assessment Tool
TO&E	Table of Organization and Equipment

USMC	United States Marine Corps
VBA	Visual Basic for Applications

EXECUTIVE SUMMARY

The Marine Expeditionary Unit (MEU) is the U.S. Marine Corps' premiere forward-deployed force that possesses the capability to provide self-sustainment for a minimum of 15 days. This thesis takes a close look at how the U.S. Marine Corps supports expeditionary deployments. Specifically, we focus on improving the level of organic support available to deployed units. We examine the methodology used to build the class IX block embarked on ships prior to deployment. The class IX block is defined as a repository of maintenance items available on-ship throughout a deployment without external support.

Historical data pertaining to the maintenance items taken in support of MEUs was not available for analysis. The sample data used in this research is an accurate representation of an Equipment Density Listing (EDL) used in support of a deploying MEU. The desired end-state of this thesis is to present the Marine Corps with a simulation analysis tool. Based on realistic variability of input parameters in relation to the specified mission set, the tool yields a detailed distribution of possibilities. An important aspect of this tool is that it be easily accessible and relatively simple to use with minimal training. To facilitate easy dissemination, we employ our model in Visual Basic for Applications (VBA) using Microsoft Excel.

The model resulting from our research is an update of the "Readiness Based Sparing and Generator Package (GENPAC) Using Sherbrooke Methodology" developed by Steve Rollins at Marine Corps Logistics Command's (MARLOGCOM) Logistics Capabilities Center in November 2016. The GENPAC model does not explore uncertainty or employ simulation to vary demand rates for maintenance equipment. This thesis focuses on experimental designs within a simulation model. Thousands of experiments are run simultaneously varying lambda (λ); the demand rate for National Stock Numbers included in our data sets. The output of these experiments is examined to determine the significance of uncertainty in demand rates and its impact on shaping the MEU's readiness and supportability. To further explore uncertainty in demand rates, we incorporate a Bayesian approach to generating distributions for lambda based on a

defined prior. Noting the Poisson distribution, the updated model will essentially vary the Poisson parameter of maintenance items contained in the EDL to output a projected list of maintenance items needed to support the EDL. This list is used to construct the class IX block for the selected availability level. The output of the updated model undergoes rigorous statistical analysis to access its validity as a systematic approach to constructing class IX blocks.

The updated model allows users to input historical data pertaining to the RNSNs requiring support during a deployment cycle. Utilizing this data, the updated model provides a recommendation on the amount of each RNSN that should be included in the class IX block to maintain the desired availability. Our assumption that the model's forecasting power would benefit from the inclusion of uncertainty is confirmed by the Bayesian approach explored in the thesis. To account for the possible variability of lambda, we introduce randomness in lambda by sampling randomly from the Uniform distribution. Much more research is needed in how best to model the uncertainty in lambdas.

Without the inclusion of randomness in the demand rates for maintenance items, the user inevitably accepts the risk of consistently underestimating the required amount of stock to support a defined availability. The effect of uncertainty is more evident in highly demanded equipment with a tendency for the actual availability to be lower than the desired. Additionally, the inclusion of randomness in the updated model appears to allow the user to change the desired availability without great variability in the cost of providing the desired availability. We consistently noticed that the original model incurs substantial cost to gain small increases in percent availability. We note that the output of the updated model is not greatly affected by slight increases in desired availability. We are unable to ascertain why the updated model is less affected by the availability constraint. However, because we vary the Poisson parameter, we cause the expected backorder (EBO) calculation to change. Varying the EBO will affect the prioritization within the updated model and could explain the varying results of both models.

The updated model gives results that are vastly different from the original model; however, we are unable to validate or quantify the increase in forecasting power of the

updated model. The lack of historical data precludes us from comparing the updated model's results to real life data; thus, the accuracy of the model is unknown. We note the need to gather real-world data and validate both models.

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ACKNOWLEDGMENTS

I would like to extend my deepest gratitude to my thesis advisor, Professor Thomas Lucas. Your passion and dedication to educating military leaders is incomparable. Without your assistance, I question whether I would have completed this thesis and provided a tool to the Marine Corps for increasing operational readiness.

I would also like to thank my peers who offered their willingness to listen as I framed and worked on this project. Without their patience and understanding, the process of completing this thesis would have been substantially harder. Finally, I would like to thank my brother, Abidemi Adeniji, for his consistent support and motivation throughout this project. To all, my successful completion of this thesis is based on the unwavering technical, emotional, and moral foundation you provided. Thank you.

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I. INTRODUCTION

A. PREFACE

The Marine Expeditionary Unit (MEU) is the Marine Corps' quick reaction forward-deployed force in support of amphibious operations (Like, Adeimy, & Curlee, 2016). It possesses the capabilities necessary to respond expeditiously to a litany of operations to include supporting operations, direct action operations, and military operations other than war. A MEU is composed of approximately 2,200 personnel to include an aviation combat element, ground combat element, logistics combat element, and a command element. Prior to deployments, the MEU commander is tasked with determining the appropriate load-out needed for the MEU to accomplish its mission set. There are currently seven MEUs within the Marine Corps: three assigned to I MEF, three assigned to II MEF, and one assigned to III MEF. Due to the varying missions of each MEU, the equipment deployed in support of operations is unique to the specified MEU's mission. This thesis focuses on the maintenance items taken at embarkation to support the MEU's equipment. The purpose of this research is to develop a reliable metric for forecasting maintenance shortcomings and reduce the need for external support while afloat.

B. BACKGROUND

The United States Marine Corps requires a tool to improve their current process for outfitting units with maintenance parts (class IX block) for the execution of expeditionary deployments. Specifically, the method for outfitting MEUs currently doesn't encompass a systematic approach to creating class IX blocks. According to a conference call on 08 September 2016 with the Marine Corps Logistics Vision and Strategy Branch (LPV), MEUs have historically seen most of their on-hand repair parts go unused while requirements arise that force unpacked items to be delivered to the unit afloat. The time-delay in receiving the necessary repair part causes a delay in restoring readiness until the unit is able to make accommodations to pick up required maintenance items in port. Additionally, there is a limited amount of space afloat. Per LPV, the current

structure has preplanned storage for the class IX block. Historically, approximately 90 percent or more of the repair parts taken afloat go unused. In a storage-constrained environment, increasing the preciseness of the class IX block allows for increased supportability and mission readiness (Marine Corps Logistics Vision and Strategy Branch, personal communication, September 08, 2016).

Of note, the Marine Corps has three echelons of maintenance: *organic maintenance* dictates that users receive adequate training to complete repairs in stride and keep the equipment serviceable without the need of inorganic support. The onus of ensuring the availability of items needed to conduct such repairs is left to leaders at the lowest using level. *Intermediate maintenance* is once again performed on site; however, specially trained mechanics and technicians that are organic to the users unit conduct the maintenance and return the equipment to serviceable status. As with organic maintenance, the onus of ensuring the availability of the appropriate items needed to conduct the repairs is left to the discretion of the specified maintenance section. Lastly, *depot maintenance* is necessary when the other echelons of maintenance have failed to return equipment to serviceable status or if the degraded part is prescribed maintenance at the depot level by Marine Corps order or directive. Equipment needing depot maintenance is shipped to Marine Corps multi-commodity maintenance centers, or other service depots for overhaul repairs.

In relation to the class IX block provided to the MEU, only organic and intermediate maintenance will be considered. For the scope of this thesis, depot maintenance is considered contractor support and is not a consideration for the systematic approach being developed.

C. RESEARCH OBJECTIVE

The desired end-state of this thesis is to present the Marine Corps with a simulation analysis tool. Based on realistic variability of input parameters in relation to the specified mission set, the tool yields a detailed distribution of possibilities. An important aspect of this tool is that it be easily accessible and relatively simple to use with minimal training. It is important to note that most principle end-items are composed

of numerous parts critical to its proper operation. The relationship between end-items and the parts that compose it are reflected as a parent child configuration in Global Combat Support System - Marine Corps (GCSS-MC), which the Marine Corps uses to track all assets. The proper association of these relationships is critical in scoping requirements and understanding the readiness level of the end-item. Improper association of equipment within GCSS-MC creates gaps in supportability and could greatly affect the usefulness of this tool.

D. RESEARCH QUESTIONS

1. Primary Research Question

Given an Equipment Density Listing (EDL) defined cost constraint and the desired level of availability, is it possible to accurately forecast the items that are critical to a MEU's class XI block for a defined mission set?

2. Secondary Research Questions

- The current estimate for the demand rate for National Stock Numbers, which is represented as the arrival rate lambda in a Poisson distribution, lacks robustness. Can we better address the inherent uncertainty of lambda by including variability in the estimate?
- The current standard for modeling breakdown rates of Marine Corps equipment utilizes a Poisson distribution. Is there any benefit to modeling the time between breakdowns with a Weibull distribution?
- Is there a methodological process of prioritizing items that are included in a class IX block?
- Is there a possibility of reducing the EDL load without impacting performance? Can the model test and validate a planned load-out of maintenance parts?
- Given multiple EDLs for the same mission set, can recommendations be made as to the feasibility of support of each EDL?

E. SCOPE OF THESIS

The goal of this thesis is focused on using simulation to produce reliable results that can be compared to historical data to provide a tool for systematically building class

IX blocks in support of MEU operations. Emphasis is placed on MEU data gathered within the last five years which reflects the current MEU structure. It is important to note that MEU missions vary substantially; therefore, the EDL is composed of equipment that is capable of supporting various requirements that can occur during a deployment cycle. The underlining purpose of this thesis is to minimize occurrences of sparely used items in class IX blocks, therefore decreasing the amount of time mission essential equipment is degraded or unserviceable.

F. METHODOLOGY

This thesis focuses on experimental designs within a simulation model. Thousands of experiments are run simultaneously varying the Poisson failure rate, here in referred to as lambda, to yield an output distribution for data analysis. We incorporate a Bayesian approach to generating distributions for lambda based on a defined prior. Noting the Poisson distribution, the updated model will essentially vary the Poisson parameter of maintenance items contained in the EDL to output a projected list of maintenance items needed to support the EDL. This list will be used to construct the class IX block for the selected availability level. The output of the updated model will undergo rigorous statistical analysis to develop a systematic approach to constructing class IX blocks.

G. BENEFITS OF RESEARCH

This research allows MEU decision makers to plan accordingly in an effort to maintain readiness on deployments. Additionally, in a resource constrained environment this tool will limit fiscal, storage, and capability inefficiencies, thereby allowing these resources to be allocated to mission accomplishment. The intent is to integrate the updated model with a widely available interface like Microsoft’s Excel and make it available to planners at all levels within the Marine Corps.

II. BACKGROUND AND RELATED WORK

A. INTRODUCTION

This chapter gives a synopsis of completed works related to this research. Specifically, it looks at the methodology of two prior theses that are closely related to this one. Additionally, it provides a brief explanation of MEU operations with relation to supply support and the variability in deployments among the MEFs.

B. MEU CONTINGENCY OPERATION MISSIONS

The Marine Corps continuously has forward-deployed MEUs in conjunction with Amphibious Readiness Groups (ARGs) operating in locations around the globe. These units are charged with providing reactiveness and increased flexibility for the MAGTF. MEUs effectively provide a force capable of autonomously responding to a litany of scenarios in a timely manner. Additionally, MEUs possess the ability to self-sustain for a period of 15 days. MEU capabilities are tested by their ability to meet the Mission-Essential Task (MET). These capabilities are defined by Marine Corps Concepts and Programs as

1. Amphibious operations: amphibious assault, amphibious raid, small boat raid (31st MEU), maritime interception operations, and advanced force operations.
2. Expeditionary support to other operations/crisis response and limited-contingency operations: non-combatant evacuation operations, humanitarian assistance, stability operations, tactical recovery of aircraft and personnel, joint and combined operations, aviation operations from expeditionary sites, theater Signal Command (SC) activities, and airfield/port seizures.
3. Theater security cooperation operations to build the capacity of partner nations and increase interoperability (Types of MAGTFs, 2015, para. 7).

C. MEU INTERNAL SUPPLY SUPPORT

The requirement for supply support is inherent to all MEU deployments. Throughout the course of a deployment, shortfalls of equipment needed for maintenance arise and must be fulfilled in order to maintain mission capability. Commanders generally

have access to several forms of supply support to include contracted specialist, Supply Officers organic to the MEU, Naval Regional Contracting Centers, Husbanding services contractors in country, as well as other external support (Schmid, 2001). The need for several sources of support is nested in the MEU's capability requirement of responding to contingency operations (Department of The Navy, 2009). Most of the sources listed above require a relatively lengthy period of time to fulfill a requisition; however, the organic Supply Officer should ideally have the ability to sustain the MEU instantaneously to some undefined extent. Helping define the "extent" of instantaneous support could be a benefit of this study. We aim to provide commanders with the knowledge of their organic supply support's ability to maintain a level of readiness. It is important to note that the occurrences of contingency operations induces uncertainty in the initial planning process of supply support. The MEU Supply Officer can plan for the scheduled exercises and missions; however, unforeseen contingency operations and unscheduled exercises are customary and make it exceptionally difficult to plan for equipment shortfalls.

D. MEU DEPLOYMENTS

> The MEUs and their associated Amphibious Ready Groups (ARGs) will continue to provide forward presence in key regions through a combination of forward basing and rotational deployments. The MEU's strength is its ability to respond to crises as an integrated MAGTF. During the next 10 years, we must explore evolving the MEU to accommodate changes in basing, capability, capacity, as well as exploration of, prepositioned equipment, land basing, complementary force packages, and alternative platforms. The MEUs may operate in a disaggregated or split manner. While not optimal, they will be resourced to mitigate the risk when operating in this manner. (Department of the Navy & Headquarters United States Marine Corps, 2014, p. 13)

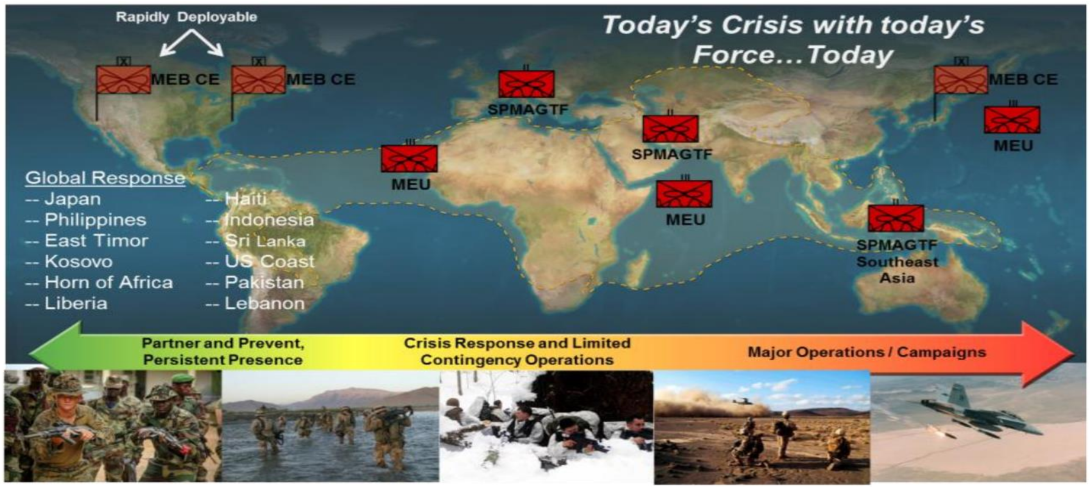


Figure 1. Projected goals for deployment of USMC assets to include MEUs. Source: Department of the Navy and Headquarters United States Marine Corps (2014).

1. I MEF MEU Missions

I MEF includes the 11th, 13th, and 15th MEU which are based out of Camp Pendleton California. Each MEU has the following mission statement:

> a forward-deployed, flexible sea-based Marine air-ground task force capable of conducting amphibious operations, crisis response and limited contingency operations, to include enabling the introduction of follow-on forces and designated special operations in order to support the theater requirements of geographic combatant commanders (U).

I MEF MEUs' areas of responsibility include the Pacific Ocean and the eastern coast of Africa. See Figure 2 for regional orientation.

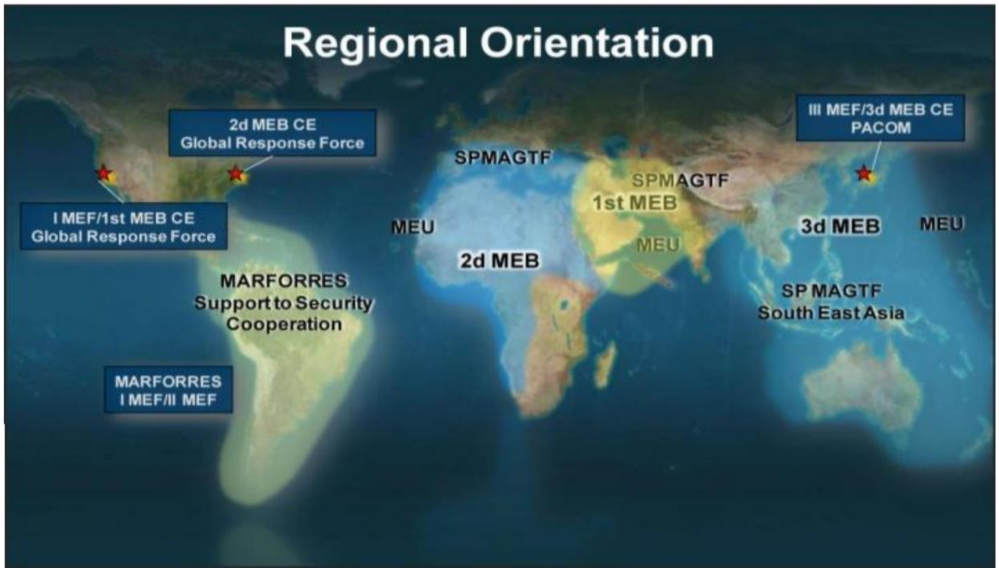


Figure 2. Regional orientation of USMC forces around the world. Source: Department of the Navy and Headquarters United States Marine Corps (2014).

2. II MEF MEU Deployments

II MEF includes the 22nd, 24th, and 26th MEU all based out of Camp Lejeune North Carolina. Each MEU possesses a specific mission set akin to the following:

> Provide geographic combatant commanders with a forward-deployed, rapid-response force capable of conducting conventional amphibious and selected maritime special operations at night or under adverse weather conditions from the sea, by surface and/or by air while under communications and electronics restrictions. (United States Marine Corps, n.d.-b.)

II MEF MEUs' areas of responsibility include the Atlantic Ocean and the Western coast of Africa.

3. III MEF MEU Deployments

Unlike I MEF and II MEF, III MEF only has one MEU. The 31st MEU is the "only continuously forward-deployed MEU" within the Marine Corps (United States Marine Corps, n.d.-d). Based out of Okinawa Japan, the 31st MEU's areas of responsibility include Asia, the Pacific and Indian Oceans, as well as Australia. The 31st MEU's mission is as follows

> well suited for amphibious operations; security operations; noncombatant operations or civilians threatened by, or suffering from, violence; and service as mobile training teams. The MEU is an expeditionary force in nature, able to operate in foreign lands without U.S. bases and facilities. It is naval in character, useful in conventional operations in the air and ashore, and is able to operate with U.S. fleets around the world. The MEU's combined arms team bears substantial force and is capable of a high degree of tactical mobility while delivering significant, sustained firepower within an objective area. (United States Marine Corps, n.d.-d)

E. LITERATURE REVIEW

1. Improving Life Cycle Management through Simulation and Efficient Design

This study examined a pre-established simulation-modeling tool utilized by the Marine Corps to examine the Course of Actions (COAs) in supporting deployed units. The Total Life Cycle Management Assessment Tool (TLCM-AT) is a process that "through identification of capability gaps, requirements generation, acquisition, fielding, sustainment, and disposal of materiel solutions" aims to ensure unity of effort by maximize equipment operational availability" (United States Marine Corps, n.d.-a) The TLCM process, while useful, lacked the ability to examine detailed scenarios for variability to changing conditions. Garcia introduces a Java-based application capable of filtering through the TLCM-AT and applying more robust Design of Experiments (DOEs) that account for small or large variations in input data (Garcia, 2008).

The tool introduced by Garcia allowed an analyst to simultaneously vary multiple parameters of a proposed scenario. This allows the analyst to determine confidence levels for outputs, as well as determine a realm of possibilities, which is defined as variations of the given scenario that maintain the desired outcome. Garcia's study shows how more robust DOEs can improve the usefulness of a model. The medium worked in is not comparable to that of this thesis; however, it does give insight to the importance of having a robust model, which is the underlining purpose of improving the current LOGCOM model to reflect the robustness generated by simulation (Garcia, 2008).

2. Inventory Optimization of Class IX Blocks For Deploying U.S. Marine Corps Combat Service Support Elements

This study conducted in 1997 focused on Operational Maneuver from the Sea (OMFTS) as a crucial element in increasing the mobility of expeditionary forces to promote increased mobility. Laforteza focuses on decreasing the logistics footprint of deployed units. The study aimed to show how a properly constructed class IX block would aid in alleviating the need for a heavy build-up of logistical support ashore. To achieve a high level of supportability, the study focused on minimizing the expected backorder for the class IX block embarked prior to deployment (Laforteza, 1997).

Laforteza (1997) implements an optimization model using operational availability, which is defined as the likelihood of having a part within the class IX block when a need arises. Although it is an optimization model, several similarities will become evident in this thesis: a Poisson distribution is used to model the number of demands; hence, we conclude that the time between demands is exponential. Additionally, the lack of data to reflect demand prevents the use of a Weibull distribution to model the distribution of the time between demands (Laforteza, 1997).

The results of Laforteza's model showed a decrease in the items on backorder, which ranged from 4 to 13 percent. It is important to note that the model only conducts six runs; therefore, we expect our results to show more variability due to the limited number of Laforteza's experiments. However, the model consistently decreased the need for logistical support when all six trials were compared to historical data (Laforteza, 1997).

F. CHAPTER SUMMARY

This chapter covered the fundamentals of MEU operations and gave some insight to the availability of supply support afloat. The reader is introduced to two previous theses that provide some further background for the problems addressed in this thesis. Upon completion of the chapter, the reader should possess a working knowledge of the MEU's position within the Marine Corps structure, as well as a strong understanding of the limitations faced in providing adequate supply support.

III. DESIGN OF EXPERIMENT DEVELOPMENT

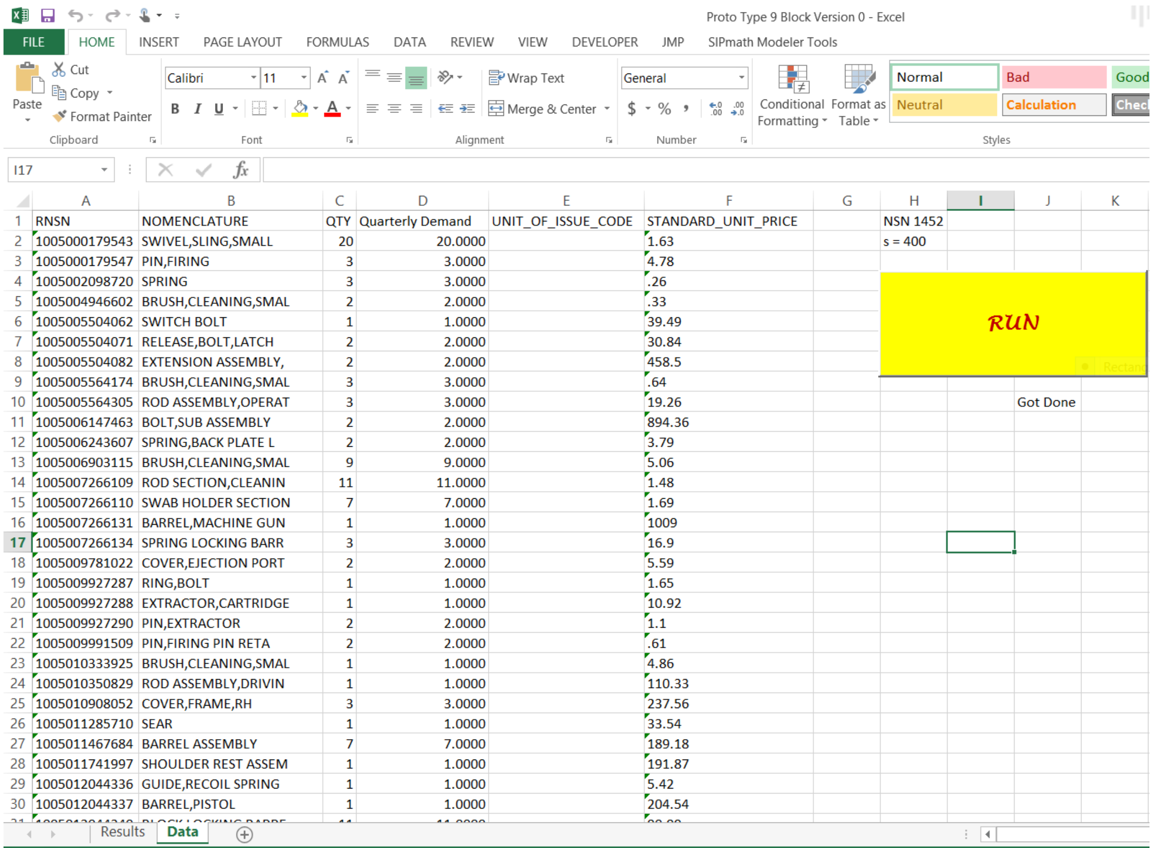
A. INTRODUCTION

This chapter covers previous work conducted by Steve Rollins in creating the original model, the updates made to the original model, and the process of inducing randomization. We provide details on the formulas used in the model, as well as the process of creating the output data. Additionally, the user form is explained in detail. Upon reading this chapter, the reader should have a good understanding of how the original and updated models calculate their respective outputs and the reader should be able to navigate the updated model's user form seamlessly.

B. THE MODEL

1. Readiness Based Sparing and GENPAC Using Sherbrooke Methodology (Original Model)

The updated model is an extension of the "Readiness Based Sparing and Generator Package (GENPAC) Using Sherbrooke Methodology" developed by Steve Rollins at Marine Corps Logistics Command's (MARLOGCOM) Logistics Capabilities Center in November 2016. The original model is implemented in Microsoft Excel 2013 and depicted in Figure 3. The original model was provided to us as a draft with plans of implementing it in another computer language to make the model run faster along with incorporating other capabilities. We focused on simplifying some of the VBA code to allow the updated model to run more efficiently. Furthermore, we chose to include additional randomness in the simulation to improve the updated model's robustness. Initially, we planned to include model simulation sampling from the Weibull distribution; however, with insufficient data and time constraints, this aspect is left for future work. Lastly, the original model lacks a user form with intuitive directions for easy navigation. We improve this in the updated model.



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3	1005000179547	PIN,FIRING	3	3.0000		4.78		
4	1005002098720	SPRING	3	3.0000		.26		
5	1005004946602	BRUSH,CLEANING,SMAL	2	2.0000		.33		
6	1005005504062	SWITCH BOLT	1	1.0000		39.49		
7	1005005504071	RELEASE,BOLT,LATCH	2	2.0000		30.84		
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10	1005005564305	ROD ASSEMBLY,OPERAT	3	3.0000		19.26		
11	1005006147463	BOLT,SUB ASSEMBLY	2	2.0000		894.36		
12	1005006243607	SPRING,BACK PLATE L	2	2.0000		3.79		
13	1005006903115	BRUSH,CLEANING,SMAL	9	9.0000		5.06		
14	1005007266109	ROD SECTION,CLEANIN	11	11.0000		1.48		
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18	1005009781022	COVER,EJECTION PORT	2	2.0000		5.59		
19	1005009927287	RING,BOLT	1	1.0000		1.65		
20	1005009927288	EXTRACTOR,CARTRIDGE	1	1.0000		10.92		
21	1005009927290	PIN,EXTRACTOR	2	2.0000		1.1		
22	1005009991509	PIN,FIRING PIN RETA	2	2.0000		.61		
23	1005010333925	BRUSH,CLEANING,SMAL	1	1.0000		4.86		
24	1005010350829	ROD ASSEMBLY,DRIVIN	1	1.0000		110.33		
25	1005010908052	COVER,FRAME,RH	3	3.0000		237.56		
26	1005011285710	SEAR	1	1.0000		33.54		
27	1005011467684	BARREL ASSEMBLY	7	7.0000		189.18		
28	1005011741997	SHOULDER REST ASSEM	1	1.0000		191.87		
29	1005012044336	GUIDE,RECOIL SPRING	1	1.0000		5.42		
30	1005012044337	BARREL,PISTOL	1	1.0000		204.54		

Figure 3. Readiness based sparing (interface).

The original model takes in six variables as input:

1. National Stock Number (RNSN) – "A 13 digit number that is used to identify items, and is assigned by the Federal Logistics Information System (FLIS) to convey specific information about an item of supply. It is comprised of the Federal Supply Class (FSC), which is four digits, and the NIIN, which is nine digits." The identifier is unique to an item and never replicated even for highly similar items. (Commandant of the Marine Corps, 2014, p. 2-1).

2. Nomenclature – The name associated with the item. Nomenclatures are not unique; several RNSNs can have the same nomenclature.

3. Quantity (QTY) – Pertains to the quantity on the MEU's EDL at embarkation; this is also referenced as the "on-hand" quantity at embarkation.

4. Demand – Gives the number of items that were requisitioned during a MEU's deployment cycle. As aforementioned, MEU missions are widely

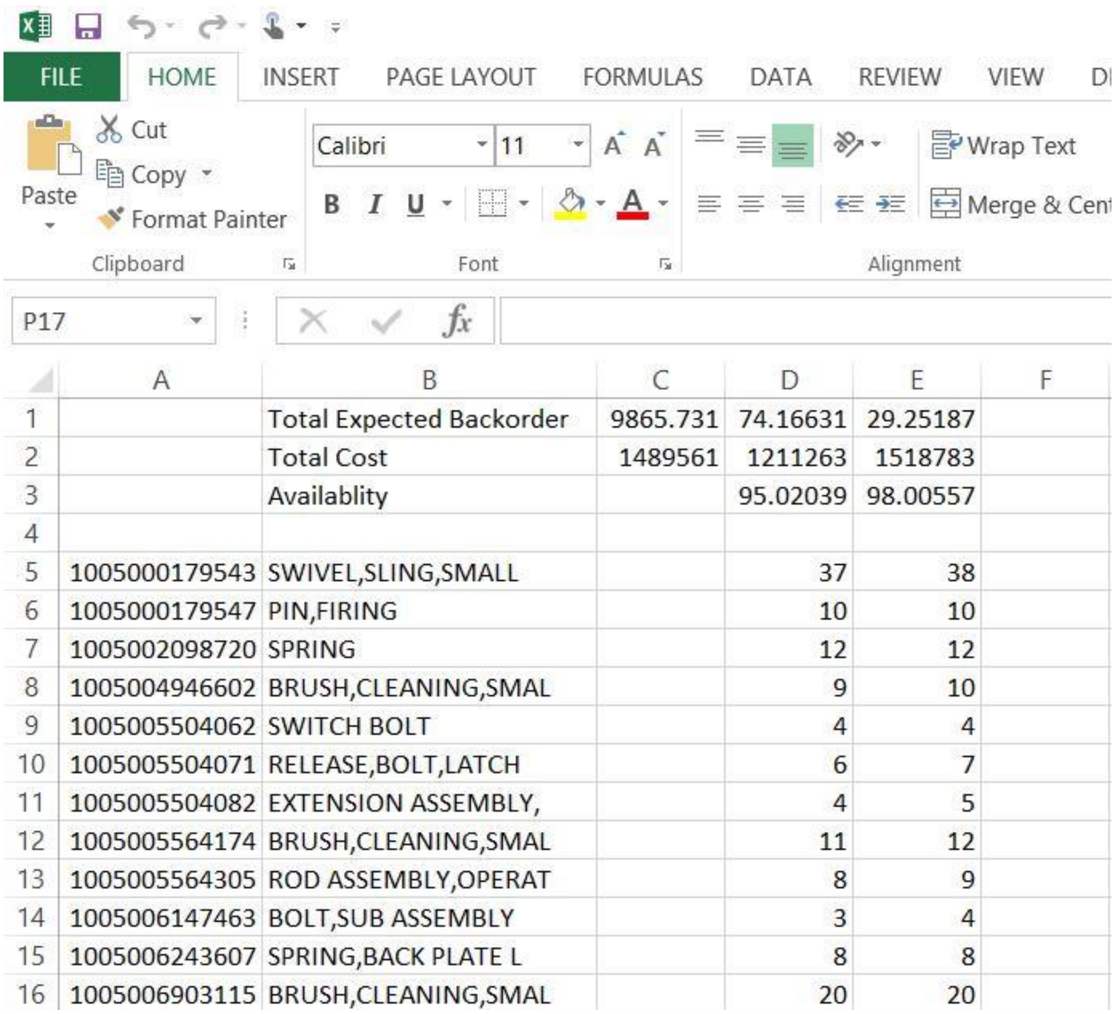
varied and inherently reactive in nature; therefore, demand does not account for the types of missions encountered when deployed.

5. Unit of Issue Code – Pertains to the number of a given item contained in a single order. For instance, the unit of issue for nails would likely be box (BX), while the unit of issue of a firing pin would likely be each (EA).

6. Standard Unit Price – The standard unit price always pertains to the price of an item in its appropriate unit of issue. That is to say, the standard unit price for nails pertains to the price of the box and not the individual nails.

The demand provides the mean per unit time (λ) of a Poisson distribution. Given the mean, the original model calculates the number of breakdown occurrences. Based on the random number of breakdowns and the initial quantity on-hand, the original model then calculates the deficit of a needed item as a backorder. The backorder in conjunction with the unit price is used to determine the price of achieving a prescribed level of readiness.

Figure 4 shows the output of the model. The user is given a listing of the quantities of each item needed to maintain an overall readiness of 95 percent and 98 percent for the class IX block. The output also reflects the cost of maintaining these readiness levels, as well as the total amount of items needed to meet the defined readiness level.



	A	B	C	D	E	F
1		Total Expected Backorder	9865.731	74.16631	29.25187	
2		Total Cost	1489561	1211263	1518783	
3		Availablity		95.02039	98.00557	
4						
5	1005000179543	SWIVEL,SLING,SMALL		37	38	
6	1005000179547	PIN,FIRING		10	10	
7	1005002098720	SPRING		12	12	
8	1005004946602	BRUSH,CLEANING,SMAL		9	10	
9	1005005504062	SWITCH BOLT		4	4	
10	1005005504071	RELEASE,BOLT,LATCH		6	7	
11	1005005504082	EXTENSION ASSEMBLY,		4	5	
12	1005005564174	BRUSH,CLEANING,SMAL		11	12	
13	1005005564305	ROD ASSEMBLY,OPERAT		8	9	
14	1005006147463	BOLT,SUB ASSEMBLY		3	4	
15	1005006243607	SPRING,BACK PLATE L		8	8	
16	1005006903115	BRUSH,CLEANING,SMAL		20	20	

Row five and below reflect the stock level needed to maintain the 95 percent and 98 percent availability for the RNSNs in column A. For instance, for RNSN 1005000179543 (SWIVEL, SLING, SMALL), the model's output implies 37 are needed to maintain 95 percent availability and 38 are needed to maintain 98 percent availability.

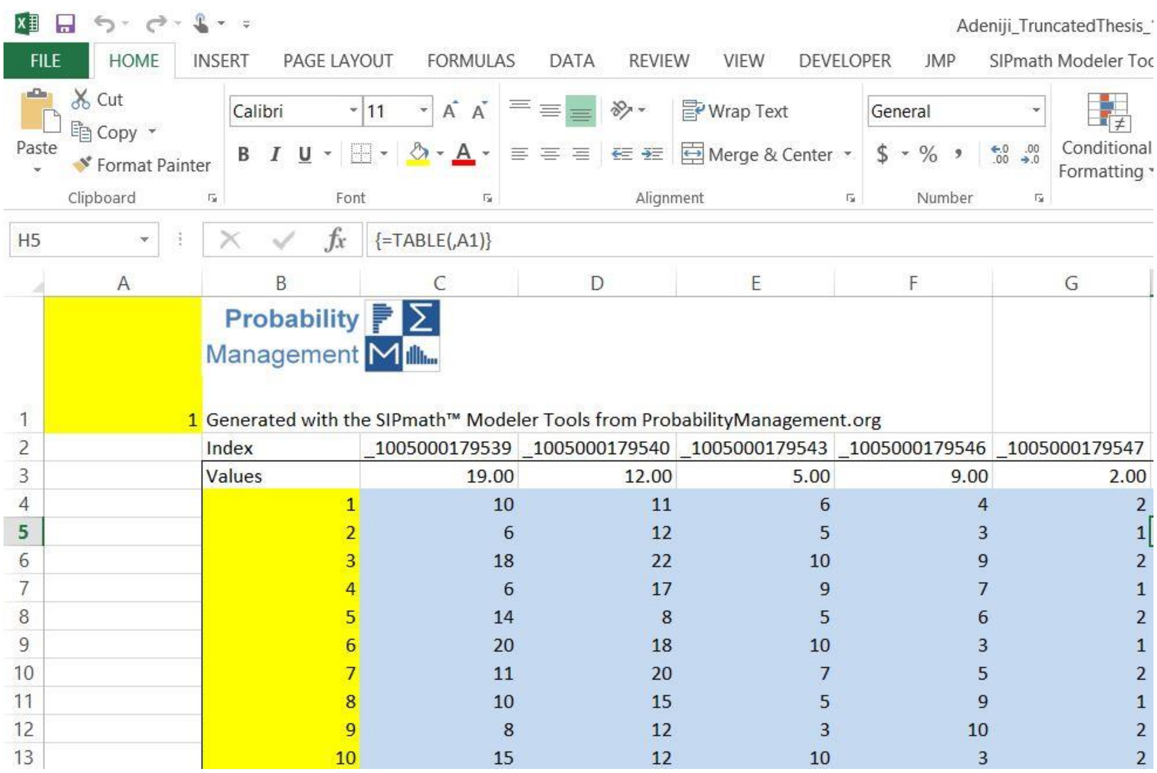
Figure 4. Readiness based sparing (output).

2. Updated Model

The "Developer" and "SIPmath Modeler Tools" add-ins were used and integral to inducing randomness within the updated GENPAC model. The Developer add-in allows for easy access to Visual Basic for Applications (VBA) coding and is available within the Excel "options" tab. The add-in aided in the development and implementation of the user form. The SIPmath Modeler Tools add-in facilitated the implementation of Monte Carlo simulation. The add-in generates the prescribed number of simulation runs and provides

output within an Excel worksheet for ease of access and analysis (Savage, 2017). A graphical representation of SIPmath output is reflected in Figure 5.

Of note, the process of determining the availability level and cost associated with the availability remains consistent with that of the original model. The key difference in how the updated model operates is the induced randomization of uncertainty in the Poisson parameter passed into the formulation. An in-depth explanation of how availability, expected backorder, and cost are calculated is outlined in Section 2b, “model explanation.”



	A	B	C	D	E	F	G
1		1	Generated with the SIPmath™ Modeler Tools from ProbabilityManagement.org				
2		Index	_1005000179539	_1005000179540	_1005000179543	_1005000179546	_1005000179547
3		Values	19.00	12.00	5.00	9.00	2.00
4		1	10	11	6	4	2
5		2	6	12	5	3	1
6		3	18	22	10	9	2
7		4	6	17	9	7	1
8		5	14	8	5	6	2
9		6	20	18	10	3	1
10		7	11	20	7	5	2
11		8	10	15	5	9	1
12		9	8	12	3	10	2
13		10	15	12	10	3	2

Each column represents a different item as reflected by the item name in row three. Rows highlighted in yellow represent the number of runs from the Monte Carlo simulation. The blue field represents the actual result of the specified run. For example, cell C4 is the output of the first run for item 1005000179539.

Figure 5. Output of SIPmath add-in.

The updated model utilizes a random number generator to generate a distribution of estimated lambdas for use in calculating the number of breakdowns. The updated model works with comma separated data (CSV) that can be loaded to an excel worksheet

and copied to the appropriate (Data) sheet. The user is given headers to guide (columns highlighted in green in Figure 6) in placing the data into the model properly. However, the updated model also allows the user to place “raw data” directly from GCSS-MC into a separate worksheet within the same workbook. The updated model will filter through the columns of the GCSS-MC data and transfer the required input data to the green fields reflected in Figure 6. Figure 6 shows the proper placement of data in the model. The Equipment Density Listing (EDL) used contains over 2,000 items and is an accurate representation of an EDL used by a MEU.

	A	B	C	D	E
1	RNSN	NOMENCLATURE	QTY	Quarterly Demand	STANDARD_UNIT_PRICE
2	1005000179539	PAWL,AMMUNITION FEE	11	11	4.63
3	1005000179540	DETENT,PAWL	11	11	.46
4	1005000179543	SWIVEL,SLING,SMALL	5	5	1.63
5	1005000179546	HANDLE ASSEMBLY,CHA	5	5	17.61
6	1005000179547	PIN,FIRING	1	1	4.78
7	1005000179548	CATCH,BOLT	1	1	12.09
8	1005000562201	CATCH,MAGAZINE	2	2	4.41
9	1005000562247	PLUNGER,BOLT CATCH	1	1	.51
10	1005000878998	RING,SLIP,HAND GUAR	1	1	4.45
11	1005002098720	SPRING	7	7	.26
12	1005002099691	SPRING	5	5	.84
13	1005003050725	SPRING,HELICAL,TORS	3	3	.51
14	1005003127177	SLING,SMALL ARMS	6	6	10.75
15	1005003488653	CHARGER,GUN	1	1	972

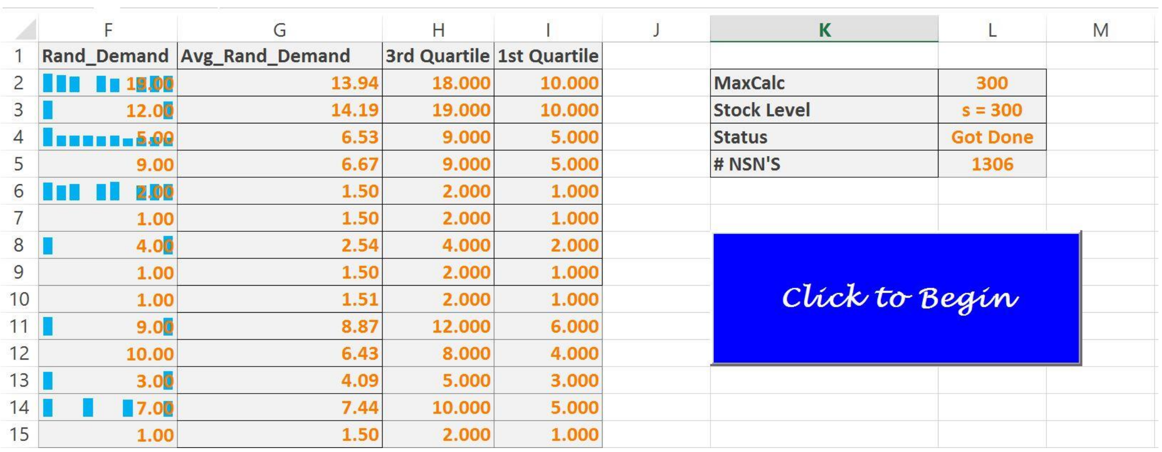
Figure 6. Graphical representation of input data.

a. Randomness

To introduce randomness in the model, the SIPmath tool is used to run one thousand Monte Carlo simulations for each item on the EDL. Each Monte Carlo simulation generates a random value for the parameter lambda, the failure rate for each RNSN, based on the initial estimate deduced from the data provided. In the original model, lambda is treated as a known constant. From our research, we notice that there is substantial variability in the lambda parameter across MEUs; therefore, we attempt to account for this uncertainty by selecting lambdas that are within a factor of two times the

original estimate. To be explicit, if the estimated value of lambda based on the provided data is four, our simulation produces 1,000 lambdas from the Uniform distribution within the range of two and eight. By using a factor of two, we hope to capture the inherent randomness in the estimate of lambda and show how such variability can affect the model's output. Once we have a random lambda, a random number of parts demanded can be generated. Note: other possible distributions on lambda are discussed later.

According to Rollins, the demand amounts of items on an EDL follow a Poisson Process (Rollins, 2016), this assumption is supported by earlier studies to include Sherbrooke's book, *Optimal Inventory Modeling* (Sherbrooke, 2004). The Poisson Process is accepted as the standard for Marine Corps' demand distribution for the number of failures (Rollins, 2016). Figure 7 depicts the application and results of the Monte Carlo simulation as it is used as an input parameter for the model.



The data reflected in columns F through I are estimates on lambda, the breakdown rate of the specified item. In cell F2, the number "19.00" reflects the result of the last simulation run. The distribution seen in blue is the graphical representation of all 1,000 runs of the simulation. We see that the graphic is approximately uniform which confirms the distribution of the randomness induced in the model. Cell G2 gives the average of all 1,000 runs, cell H2 gives the cut off for the 3rd quartile from the 1,000 estimated lambdas. We expect 25 percent of the estimated lambdas for this item to be greater than 18. Cell I2 gives the cut off for the 1st quartile from the 1,000 estimated lambdas. We expect 25 percent of the estimated lambdas for this item to be less than 10. Items reflected in the graphic to the right of column J will be addressed in later parts of this thesis.

Figure 7. Graphical representation of randomness data.

b. Model Explanation

The standard probability mass function (PMF) for a Poisson distribution is as follows:

$$p(x) = \frac{(e^{-\lambda})(\lambda^{x})}{x!} \tag{1}$$

Here, *x* is the number of parts demanded and lambda is its expected value. The model does not account for the operational status of RNSNs. That is, whether a system has failed has no impact on the arrival of another failure. Rollins breaks down this formulation into one that is better suited for calculations within the model. Notice that the value of $e^{-\lambda}$ never changes being that e is a constant and λ is the mean arrival rate for some item. λ^{x} and $x!$ will change in reference to the desired level of occurrences (*x*). To simplify the PMF for VBA computational purposes we utilize Rollin's simplification (Rollins, 2016):

$$p(n) = p(n-1)\frac{\lambda}{n} \tag{2}$$

Here we define *p(n)* as the probability of needing exactly *n* items. This formulation accounts for all values of *n* that are greater than zero, where *p(0)* is simply $e^{-\lambda}$, as follows from Equation (1) (Rollins, 2016).

Equation (2) is summed over all values less than or equal to *n* to calculate the probability of needing *n* or less items, the updated model calculates the probability until *n* is large enough that the desired readiness level needed for the given item is achieved.

Using the calculated probabilities, we then need to calculate the deficit between items on-hand and the amount needed to meet the required readiness level. Rollins equates this deficit to the Expected Backorder (EBO). To calculate the backorder we utilize Equation (3) (Rollins, 2016):

$$EBO(s) = \sum_{x=s+1}^{\infty} (x-s)\,p(x) \tag{3}$$

In Equation (3), "*s*" represents the stock of a given RNSN, which is the number that should be included in the class IX block. Notice that we sum over all possible values of demand greater than the number originally in stock, "*s*." Within the updated model "infinity" is equivalent to "maxcalc," which we programmed to be the highest on-hand quantity on the EDL multiplied by two. This was done intentionally to allow the updated model to run faster. "maxcalc" proved to be adequate in producing the necessary output. For example, if in one of our datasets, the max on-hand quantity is 486, then in such a case maxcalc = 972. The probability that a Poisson distribution with λ = 486, i.e., the worst case, is greater than 675 is on the order of 10^{-16}. Maxcalc can be changed and hardcoded by the user. "*s*" is the amount of a certain item we included in the class IX block or stock. Equation (3) is calculated until we have a stock level that results in an EBO close to zero. The values associated with each level of stock leading to an EBO of zero are used to determine the priority of adding items to add to the class IX block.

Using the EBOs calculated with Equation (3), we now calculate the marginal reduction associated with *adding items to the class IX* block. The marginal reduction is essentially the reduction associated with adding an additional item to stock; that is of going from EBO(s) to EBO(s+1) divided by the cost of the item. Equation (4) shows how we calculate marginal reduction.

$$Mar\,\mathrm{Re}\,du = \frac{EBO(s) - EBO(s+1)}{\mathrm{Cos}\,t} \tag{4}$$

In an effort to induce some element of prioritization, we use the marginal reduction to determine when an item is added to the class IX block. For example, suppose we have two items. Item one has λ =0.5 with a cost per item of one dollar and item two has λ =10 with a cost per item of five dollars. We calculate the change in EBO in relation

to stock levels and use this change to determine the marginal reduction. The associated EBO are reflected in Table 1.

Table 1. EBO(s) for both items.

Stock (s)	EBO_Item1	EBO_Item2
0	0.5	10.0
1	0.1065	9.0
2	0.0163	8.0

We then calculate the marginal reduction for increasing the stock of both items from zero to one using Equation (4).

$$Mar\,\mathrm{Re}\,du\_Item1 = \frac{0.5 - 0.1065}{1} = 0.3935$$

$$Mar\,\mathrm{Re}\,du\_Item2 = \frac{10.0 - 9.0}{5} = 0.20$$

From the calculation, notice the marginal reduction of item two (0.20) is lower than item one (0.39), thus item one is added to stock. If we repeat this process we notice the marginal reduction of increasing item one from one to two (0.0902) is lower than the reduction gained by increasing the stock of item two from zero to one (0.20). In this instance, we increase the stock of item two. Table 2 gives the marginal reduction associated with increasing the stock level of each item (Rollins, 2016).

Table 2. Marginal reduction associated with both items.

Stock (s)	MarRedu_Item1	MarRedu_Item2
0	---------------------	---------------------
1	0.3935	0.20
2	0.0902	0.1999

We note that the readiness level desired as defined in Equation (5), is used as a constraint rooted in the EBO and *p(x)* calculations. Based on this constraint, the marginal reduction is examined and the item having the highest marginal reduction is added to the class IX block. Equation (5) shows how availability is calculated. For clarity, we define availability as the overall readiness induced by the class IX block. That is, given all the RNSNs being supported on the EDL, the class IX block on average will maintain stocks capable of replenishing RNSN failures at the user dictated availability. This process of adding RNSNs to the class IX block is repeated until the required availability is achieved (Rollins, 2016). The resulting stock levels along with the total price of the goods included in the class IX block are reflected in the "StocResults" worksheet.

Lastly, we examine the overall availability of the system based on Sherbrook's determination of Supply Availability. Sherbrook defines Supply Availability as:

$$A_s \cong 100 * \left(e^{-\sum_{i=1}^{N} \frac{EBO_i(s_i)}{N}} \right) \tag{5}$$

where N is the total number of RNSNs examined and "*i*" pertains to the RNSN being examined.

Equation (5) is the standard accepted at MARLOGCOM and is accepted for our updated model (Sherbrooke, 2004, p. 93). We note that the use of Equation (5) leads to instances of overestimating the stock level depicted in the output of both models. This occurs because of the prioritization induced in both models by Equation (4) that forces items to be be added to stock in relation to their ability to reduce EBO. Instances occur when a specific RNSN's availability is satisfied; however, increasing the stock of the defined RNSN still results in the largest marginal reduction to the EBO. This process allows for the overall availability, A_s, to be reached while minimizing the cost of the class IX block. A proposed update to both models could be to individually calculate the tail probabilities of the Poisson cumulative distribution function associated with each lambda

and the required availability. The process would likely increase the cost of any class IX block constructed while still not addressing the inherent variability in lambda; however, we believe this approach could significantly decrease over-stocking RNSNs because it removes the need for prioritization . Pseudocode pertaining to the general construct of building a model with exact calculations for stock based on availability is included below. The pseudocode is created with the intent of being implemented in Visual Basic for Applications, but can easily be adopted into other computer languages.

```
Ava = list of availabilities to be evaluated
Max_calc = user defined list
i = 0
Array[1] = lambdas
Array[2] = [ ] empty list to hold stock levels needed to meet availability
For( i in lam bdas){
        QtPoisson = 0
        X = 0
        For( X in max_calc){
                QtPoisson = worksheetfunction(X, Array[i], TRUE)
                If (QtPoisson >= Ava[i]){
                        X = Max_calc[i]
                        Break
                }
        }
        Array[2] =X
}
```

QtPoisson uses Excel's built in worksheet function to calculate the probability of needing *X* or less of an RNSN given the corresponding lambda. We then compare *QtPoisson* to the desired availability to determine if *X* is an adquate stock level to maintain the required availability of the RNSN being examined. If *X* does satisify the requirement, the value associated with *X* is stored as the stock needed for that RNSN.

c. User Form

The user is presented with a simple interface containing brief instructions on input parameters. It is assumed that the user possesses a working knowledge of the model, thus only a cursory explanation of each input is provided on the user form. The user form

contains three categories; Availability desired, view itemized breakdown, and robustness. A graphical representation of the user form is reflected in Figure 8.

The user can choose from nine readiness levels. Once an option button is selected, the run button will populate a message box with the cost of composing a class IX block that meets the desired availability as calculated by Equation (5), as well as a raw estimate of the quantity of items that compromise the class IX block. The user is also given the option to view an itemized listing of parts included in the class IX block pertaining to the availability level selected, as well as the unselected levels. This is done intentionally to facilitate easy comparison. This output populates to a worksheet named "StocResults." The final category on the user form pertains to the randomness of the results. While the updated model's output is inherently random, this category controls whether the output of the model changes with subsequent runs.

The deterministic selection will yield the same output results every time the updated model is run. However, it is important to note that although the output is consistent, the output is based on seeded simulation runs from the Poisson distribution. This is done intentionally to maintain the robustness of the results while allowing the user to have the option of receiving quick results. The Random option will output different results with every run. The option buttons listed in this category essentially activates and deactivates automatic calculations within the workbook.

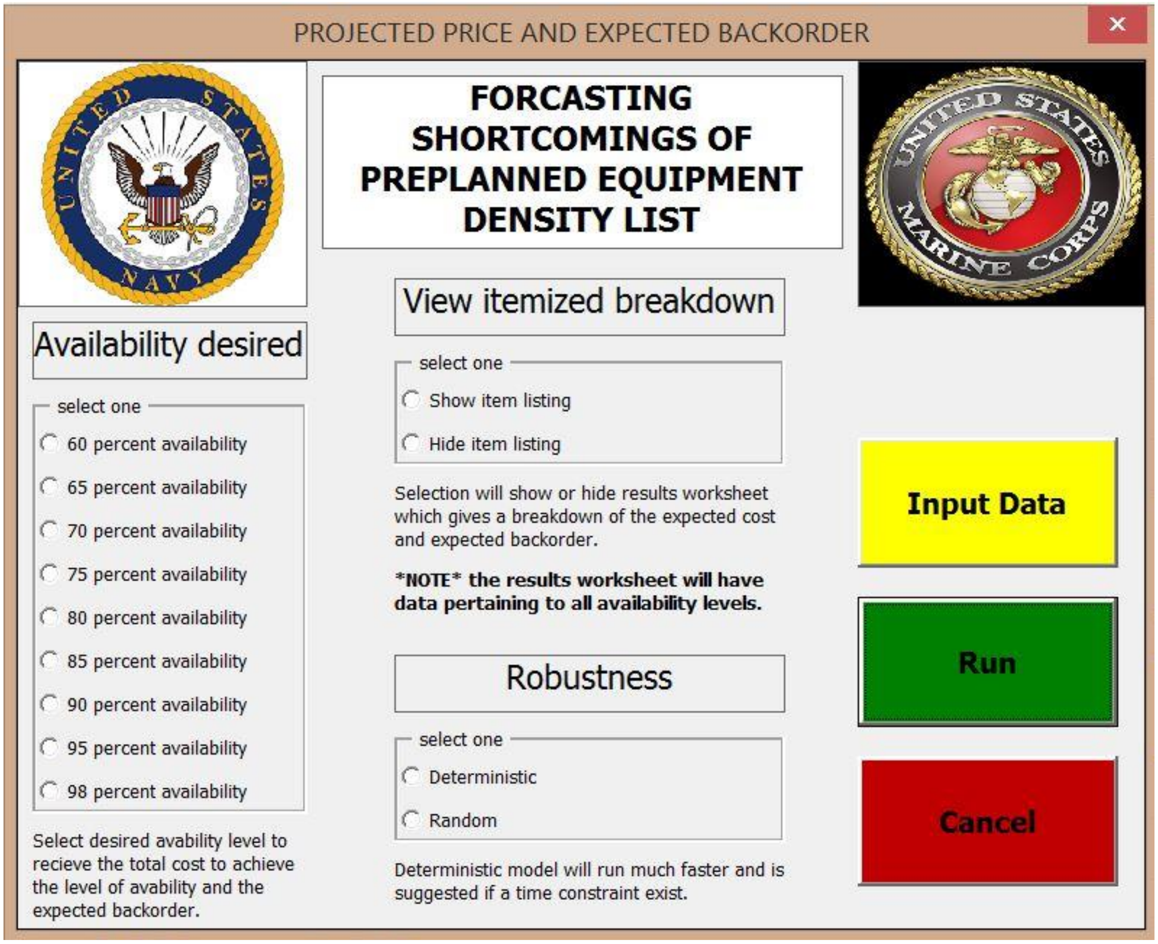


Figure 8. The user form allows the user to select the parameters to be reflected in the output data.

d. Updated Model Output

The updated model outputs a message box with total cost and total number of items needed as aforementioned. This is the only output the user will receive if the "Hide item listing" button is selected. This option is intended for quick analysis such as determining if an availability level is feasible under a cost constraint. A graphical representation of the message box is reflected in Figure 9. If more detail is required, the user is expected to select the "Show item listing" button.

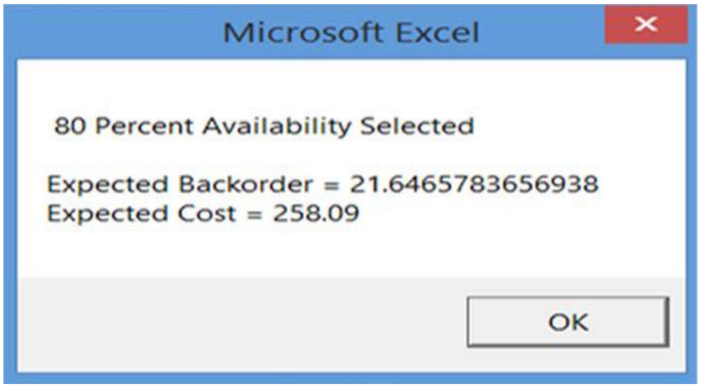


Figure 9. Message box reflecting results.

The “StocResults” worksheet has 11 columns of data. The first two columns give the National Stock Number (RNSN) and nomenclature. Columns D through L give respective costs, availability, and expected backorder associated with each availability level. This worksheet is the models greatest asset as it allows the user to compare the different load outs and costs of each readiness level. The user can then make informed decisions pertaining to the proper load out to sustain a specific mission set while understanding the risk being accepted by choosing the prescribed readiness level. This in-depth understanding of equipment shortcomings is a vital part of any supply related process or supportability procedure.

	A	B	C	D	E	F	G	H	I	J
1				AVERAGE	1st QUANTILE	3rd QUANTILE		AVERAGE	1st QUANTILE	3rd QUANTILE
2		Availablity		60.0	60.0	60.0		65.0	65.0	65.0
3		Total Cost		$469,455.00	$ 347,486.00	$ 401,047.00		$489,176.00	$ 368,722.00	$ 422,076.00
4		Total Expected Backorder		666	666	666		562	562	563
5										
6	1005000179539	PAWL,AMMUNITION FEE		20	15	25		20	15	25
7	1005000179540	DETENT,PAWL		21	16	27		21	16	27
8	1005000179543	SWIVEL,SLING,SMALL		12	10	16		12	10	16
9	1005000179546	HANDLE ASSEMBLY,CHA		12	10	16		12	10	16
10	1005000179547	PIN,FIRING		5	4	6		5	4	6
11	1005000179548	CATCH,BOLT		5	4	6		5	4	6
12	1005000562201	CATCH,MAGAZINE		6	5	9		6	5	9
13	1005000562247	PLUNGER,BOLT CATCH		5	4	6		5	4	6
14	1005000878998	RING,SLIP,HAND GUAR		5	4	6		5	4	6
15	1005002098720	SPRING		14	10	18		14	10	18
16	1005002099691	SPRING		12	9	15		12	9	15
17	1005003050725	SPRING,HELICAL,TORS		9	7	10		9	7	10
18	1005003127177	SLING,SMALL ARMS		12	9	15		12	9	15
19	1005003488653	CHARGER,GUN		5	4	6		5	4	6
20	1005003504100	BRUSH,CLEANING,SMAL		5	4	6		5	4	6

Figure 10. Graphical representation of results spreadsheet.

C. PARAMETERS

The user needs to provide adequate data for the updated model to perform properly. DATA FILTER was developed as a tool to calculate lambda based on a generic GCSS-MC equipment listing. The GCSS-MC equipment listing will contain 29 columns of data in its standard format. The user must ensure the data is arranged appropriately for the DATA FILTER to function properly. The data needed for the filter should be in the following form:

1. SHIP_TO_ORG
2. RNSN
3. NOMENCLATURE
4. DOCUMENT_NUMBER
5. DOC_ID_CODE
6. QTY
7. DATE_ESTABLISHED
8. LKH
9. CANC_QTY
10. SHIP_QTY
11. STATUS_DATE
12. AS1_DAYS
13. RECEIPT_QTY
14. STATUS_DATE_1
15. D6T_DAYS
16. SR_NUMBER
17. ITEM_TYPE
18. SERIAL_CONTROL_FLAG
19. LOT_CONTROL_FLAG
20. IB_TRACKABLE_FLAG
21. FLOAT_IND
22. STORES_ACCOUNT_CD
23. STANDARD_UNIT_PRICE
24. ACQ_ADVICE_CD_MC
25. COMBAT_ESSENTIALITY_CODE
26. CNTRL_INVENTORY_ITM_CDE
27. RECOVERABILITY_CODE
28. SHELF_LIFE_CODE
29. IDN

The order listed above reference the appropriate columns within the worksheet, that is, columns A, B, and C in the worksheet correspond to SHIP_TO_ORG, RNSN, and

NOMENCLATURE respectively (Rollins, 2017). This association is consistent for the entire list of headers. The Data Filter was originally a separate program that required the user to move data between workbooks, as well as, delete unneeded columns. All elements of the Data Filter are now integrated into the updated model and require the user to input data only once. The user is only required to place data in the “raw data” worksheet, with the data properly placed in the worksheet, the updated model will filter through the columns of data provided using DATA FILTER and automatically populate the data appropriately in the updated model.

If the user’s data is already in the appropriate format needed for the model, the user can simply cut and past the data into the green fields on the “Data” worksheet and click “Calculate Now.” “Calculate Now” is found under the “Formulas” tab along the top of the Excel workbook. The user should not use the “Input Data” button in this scenario, but proceed as normal with running the program.

D. MEASURE OF EFFECTIVENESS

To measure the effectiveness of the updated model, we compare the updated model’s results to historical data of MEUs. By doing this, we are able to measure how accurate the updated model’s output is in reference to the MEU’s requisitions afloat. Ideally, we would like to compare our modeled class IX block to the actual class IX block taken on the MEUs; however, the required data was not available. We recommend that MEU data be gathered and stored for further evaluation.

E. SIMULATION RUNS

As previously stated, the model’s randomness is rooted in the SIPmath add-in, which we used to conduct Monte Carlo simulation. So what exactly is a Monte Carlo simulation? “Monte Carlo simulation, or probability simulation, is a technique used to understand the impact of risk and uncertainty in financial, project management, cost, and other forecasting models” (Structured Data, 2017). In any forecasting model, there is inherent uncertainty associated with the model’s output. This uncertainty is inpart due to the assumptions built into the model; for instance, we assume that there will be some demand for maintenance items during the conduct of a MEU. This assumption requires us

to make an "educated guess" about the demand rate for these items. Knowing that these demands will occur in the future, our educated guess is an estimate of the expected value. While the expected value is calculated from historical data, in our case of a single deployment, there is still uncertainty associated with our estimate of the number of demands because the actual value is unknown. In addition, MEU's missions change. The Monte Carlo simulation allows us to draw random samples from a defined distribution. For this thesis, we draw 1,000 random samples from a Uniform distribution for each RNSN being evaluated. These random samples are used as an estimate of lambda, the expected value of the number of demands per unit time. Each iteration gives us an observation; the conglomerate of all iterations gives us a distribution that includes the extreme values we can expect from our original estimation of the expected value. This allows us to examine how likely we are to see a certain outcome (Structured Dat, 2017).

Historical data is used to calculate an estimate of lambda used as an input to the original model. This lambda estimate is varied using the Uniform distribution to generate our 1,000 iterations. Utilizing our simulated values, we examine the first quartile, mean, and third quartile of the simulated runs and use all three as estimates of lambda in the updated model. These values, reflected in columns "G" through "I" on the "Data" worksheet are used for our *p(x)* and EBO calculations.

F. CHAPTER SUMMARY

This chapter gives a truncated synopsis of the original model by Rollins adopted for this thesis. Additionally, we address how the original model is modified to introduce randomness and the benefits of utilizing a Monte Carlo simulation. Lastly, we describe the user form in detail and the reader is given enough information to be able to operate the updated model autonomously.

IV. DATA ANALYSIS

A. INTRODUCTION

This chapter covers the results of both models. Attention is given to the differences in output to access the usefulness of simulation in forecasting the breakdown rates of MEU equipment. Additionally, we will attempt to show how a variance in the estimated lambda parameter can have a significant influence on the results of both models. We also cover the difficulties encountered in gathering reliable data for processing. Recommendations are given to aid in the storage of data for future research.

B. DATA COLLECTION

As aforementioned, the foundation of this thesis is based on the availability of useful historical data pertaining to MEUs deployed in the last five years. Upon gathering data for this thesis, several areas of concern present themselves:

1. The construct of the MEU is not conducive to maintaining appropriate historical files.
2. The data used in LOGCOM's (original) model and the updated model used for this thesis are not completely "real" data.
3. The process for formulating the estimate of lambda can highly influence the model's output.
4. The availability of time-step data would aid greatly in furthering the research on life cycles of USMC equipment.

To begin, the MEU essentially owns no equipment. The equipment needed for a MEU deployment generally belongs to other units as the MEU has no standing Table of Organization and Equipment (TO&E). Generating historical files for this equipment is difficult because the equipment is only tracked or air-marked as belonging to the MEU when the MEU is standing. Once a MEU returns from a deployment, all equipment is returned to the owning agency; thus gathering historical information on a since dissolved MEU is very difficult. While we do not recommend that the Marine Corps maintain all MEUs continuously, we do attest that maintaining an electronic listing of all equipment

taken on MEUs to include their class IX blocks is essential to accurately forecasting future MEU requirements, a prerequisite to efficiently supplying them.

The data required for the updated model includes information pertaining to the on-hand quantity of equipment at embarkation. This data requirement is needed to calculate supportability; that is, to properly access how much maintenance support an item might need during a given period, we must first begin with how many items are being supported. Due to a lack of historical information on equipment embarked on MEUs, the updated model assumes the RNSNs ordered during the course of the deployment is equal to the RNSNs stocked as maintenance equipment at embarkation. While the assumption does present the possibility of error, it is not too obscure of an assumption to make. Marine Corps supply operations dictate the replacement of an item once one is removed from a maintenance part storage. In the case of the MEU, every item removed from the class IX block should be ordered in a timely manner to replenish the class IX block and maintain supportability. Therefore, the assumption does not account for RNSNs that were unused within the class IX block, but has some legitimacy in predicting the RNSNs that were organic to the MEU at embarkation.

To formulate the lambdas used in the model, we utilize a transaction history report which is a document generated by GCSS-MC. This report allows us to look at all requisitions from the MEU during a deployment cycle. RNSNs with a Stores Account Code (SAC) of 2 and 3 are not considered because they come at no cost to the MEU. SAC 1 RNSNs are paid for by the unit; these RNSNs are included in calculating the price of maintaining a certain level of availability. Additionally, we look at the amount actually received by the MEU in comparison to those ordered. For any item in a given time period, the amount ordered minus the amount cancelled should equal the amount received. We use the amount received as the demand for the item within the given time period. Due to the lack of information on RNSNs included in the class IX block at embarkation, we cannot confirm if canceled quantities or quantities not received were actually needed. We are able to confirm that there was a need for the RNSNs that were requisitions and received.

Although we accept as reasonable the assumption that the number of failures for Marine Corps equipment follows a Poisson distribution, we believe that knowing the lifetime of equipment utilized on the MEU would help in forecasting requirements. Analysis into the life cycle of Marine Corps equipment would greatly increase our understanding of demand rates and supportability.

C. DATA CLEANING

The raw data received for this thesis possessed some flaws. In using the "DATA FILTER" provided by LOGCOM, we are able to get the raw data into a form that can easily be inputted into the models. However, after running the DATA FILTER, we notice that several rows of the data were missing valuable information pertaining to the RNSN being examined. Some of these RNSNs had the nomenclature or unit price information missing, while others had no RNSN or demand data at all. To produce the most reliable forecast, we eliminate all lines of data that are missing information; the lines of data eliminated account for approximately three percent or less of the available data for each MEU. The RNSNs examined are reflected in the results of the models and available for the users' reference. The data used for analysis had all relevant information needed for the model's calculation. Additionally, the updated model is coded to automatically eliminate all rows of data that have missing information. The user is cautioned to ensure data being evaluated accurately represents the RNSNs needed for the class IX block.

D. BASIC COMPARISON

For our analysis, we were able to gather requisition data for the seven MEUs deployed between February 2014 and September 2016. The data pertains to RNSNs that were ordered while the MEU was deployed. The analysis below covers each MEU separately and is presented chronologically starting with the 11th MEU. Table 3 below gives a summary of deployment dates for each MEU. Table 4 shows the total number of RNSNs included in the data available for each MEU. Tables 5 through 11 give a simple comparison of cost, expected backorder, and similarity across both models for each MEU.

Table 3. List of MEU requisition data provided for analysis.

MEF	MEU	BEGIN	END
1	11	1-Jul-14	28-Feb-15
1	13	1-Feb-16	30-Sep-16
1	15	1-Apr-15	31-Dec-15
2	22	1-Feb-14	31-Oct-14
2	24	1-Nov-14	31-Jul-15
2	26	1-Nov-15	30-Apr-16
3	31	1-Nov-15	31-Mar-16

Table 4. Number of RNSNs contained in available data.

MEF	MEU	Number of RNSNs
1	11	1306
1	13	1917
1	15	2570
2	22	1416
2	24	2903
2	26	2026
3	31	1452

It is important to take note of the variability in the number of RNSNs contained in the data set available for each MEU. Due to this variability, comparing lambdas across MEUs is relatively infeasible because RNSNs contained in one MEU data set are often not contained in another. This makes it exceptionally difficult to estimate lambda accurately when there is not consistent historical data available. Additionally, as mentioned in the previous section, we were unable to gather historical data that reflected the initial load out of each MEU; the variability in the number of RNSNs is likely due to the fact that we are using a transaction listing instead of an EDL. However, we still take note of the raw number of RNSNs requisitioned during the different MEU deployments

and conclude that the variability seen in the number of requisitions supports the need for randomness in any model that aims to forecast cost and availability.

Table 5. 11th MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$906,336.41	$1,147,146.59	$610,155.00	$638,915.00	$296,181.41	$508,231.59
Total Expected Backorder	67	26	67	26	0	0
Similarity Percentage					14.0%	14.6%

Table 6. 13th MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$1,237,904.79	$1,585,620.72	$1,191,224.00	$1,249,600.00	$46,680.79	$336,020.72
Total Expected Backorder	98	38	98	38	0	0
Similarity Percentage					11.3%	12.4%

Table 7. 15th MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$1,874,883.83	$2,349,348.77	$1,076,895.00	$1,133,051.00	$797,988.83	$1,216,297.77
Total Expected Backorder	131	52	132	52	0	0
Similarity Percentage					13.8%	14.9%

Table 8. 22nd MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$1,023,372.40	$1,287,058.50	$1,086,827.00	$1,131,745.00	$63,454.60	$155,313.50
Total Expected Backorder	73	29	73	29	0	0
Similarity Percentage					12.1%	12.6%

Table 9. 24th MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$2,468,893.86	$3,067,349.22	$3,872,526.00	$4,006,097.00	$1,403,632.14	$938,747.78
Total Expected Backorder	149	59	149	59	0	0
Similarity Percentage					21.5%	20.7%

Table 10. 26th MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$1,126,668.52	$1,489,560.51	$1,394,203.00	$1,457,524.00	$267,534.48	$32,036.51
Total Expected Backorder	104	41	104	41	0	0
Similarity Percentage					11.4%	12.8%

Table 11. 31st MEU results comparison: notice the EBO is equal across models.

	Original Model		Updated Model		Difference	
Availability	95	98	95	98	0	0
Total Cost	$1,211,263.19	$1,518,783.44	$1,311,555.00	$1,364,290.00	$100,291.81	$154,493.44
Total Expected Backorder	74	29	74	29	0	0
Similarity Percentage					13.6%	13.6%

A simple comparison of the results from both models utilizing the same data set is reflected in Tables 5 through 11. We initially notice that the total of RNSNs we expect to order during the course of a MEU deployment are generally equal across both models. This may lead to speculation that the models bear no difference in their forecasting capability. Upon further inspection, we notice the RNSNs included in the class IX block constructed by each model are significantly different. Both models agree on approximately 20 percent of RNSNs: that is, looking at each RNSN evaluated, approximately 20 percent of both models include exactly the same number of maintenance support items in the class IX block. This calculation was computed utilizing conditional statements in an Excel spreadsheet. Essentially, the conditional statement looked at the output from both models and assigned a comparison value of either one if

the outputs were not equal or zero if the outputs were similar. Figure 11 shows an excerpt from the spreadsheet used for calculating the similarity percentage.

	G	H	I	J	K
1	Difference			Number of Differences	
2	95	98		95	98
3	$267,534.48	$32,036.51			
4	0	0		11.4%	12.8%
5					
6	0	0		0	0
7	3	2		1	1
8	0	0		0	0
9	0	1		0	1
10	1	0		1	0
11	1	2		1	1
12	2	3		1	1
13	0	0		0	0
14	0	0		0	0
15	3	1		1	1
16	3	2		1	1

Rows 6 through 16 is an excerpt of the RNSNs evaluated for the MEU, this depiction shows a segment of the data to illustrate the process of calculating the similarity percentage.

Figure 11. Calculation of similarity percentage.

Columns G and H represents the absolute difference at both the 95 and 98 percent availability level for both models. Looking at cells G7 and H7, we see that the difference between the forecasted values of the two models for 95 and 98 percent availability is three and two respectively. Columns J and K utilize the conditional construct reflected in the pseudo code reflected below. The values in columns J and K are resulting from a Boolean test. If the outputs from both models are equal, the test yields a zero, otherwise,

it yields a one. Summing over columns J and K give the number of RNSNs that the models do not agree on at 95 and 98 percent availability respectfully. Taking this value and dividing it by the total number of RNSNs evaluated gives the dissimilarity percentage. Subtracting the dissimilarity percentage from one gives us our similarity percentage.

```
If (Value in column H greater than Zero) Then
   (Column K equal to one)
Else
   (Column K equal to Zero)
End If
```

Figure 12. Pseudocode for calculating Boolean parameter for similarity percentage.

E. RESULTS

By construct, the models are coded to ensure the overall availability requested is always reached. The availability serves as a constraint so comparing the availability level outputted from each model is not a relevant measurement of comparison. Additionally, the results from the original and updated models do not show significant differences when we compare the expected backorder. However, the cost associated with creating the class IX block is an important aspect of this thesis. Ideally, we aim to provide the highest level of supportability while minimizing the overall cost of the class IX block. From the analysis above, we notice that the cost associated with each model possess the greatest differences in model outputs. We also look at the similarity between the constructed class IX blocks.

We see that the updated model is generally cheaper than the original model and the similarity percentage ranges between approximately 10 and 20 percent. The following sections give a better explanation of the results pertaining to the respective MEUs.

1. 11TH MEU

Examining the 11th MEU results, we notice that the expected backorder values for both models are identical. While both models output a class IX block containing the same RNSNs, the number of each RNSN contained in the class IX block is significantly different for both models. At 95 percent availability, we see that the class IX block for both models only agree on 14 percent of the forecasted values. Moreover, at 98 percent availability, the similarity slightly increases to 14.6 percent. The cost associated with both models leads us to believe that the updated model provides the same level of support at a discounted rate. The updated model is able to provide the same level of support for approximately 67 percent of the price of the original model. Gaining the additional three percent for the original model proves to be rather expensive. The cost associated with increasing from 95 to 98 percent availability is approximately $241 thousand dollars. This accounts for a 27 percent increase in price to achieve a three percent increase in availability. Conversely, the updated model is able to achieve the same 98 percent availability level at approximately half the cost of the original model. In comparing how much the three percent increase cost for the updated model, we see that the three percent increase costs approximately five percent more. This leads us to believe that the updated model's forecasting power is not greatly affected by slight changes is the desired availability.

Table 12. Price comparison 11th MEU.

Updated Cost		
Percent of Original	0.67	0.56
Cheaper than Original (Percent)	0.33	0.44
Cost of 3% increase (Original)	$240,810.18	0.27
Cost of 3% increase (Updated)	$28,760.00	0.05

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

2. 13TH MEU

The 13th MEU results show greater similarity in the cost associated with both models. Again, we notice that the expected backorder values for both models are highly similar. As with the results from the 11th MEU we once again see the number of each RNSN contained in the class IX block for the respective models is significantly different. At 95 percent availability, we see that the class IX block for both models only agree on 11.3 percent of the forecasted values, at 98 percent availability, the similarity increases to 12.4 percent. Unlike the 11th MEU, the costs associated with both models are relatively similar to achieve 95 percent availability. However, the cost is substantially different at 98 percent availability. At 95 percent availability, the updated model is approximately four percent cheaper than the price in the original model. Gaining the additional three percent for the original model proved to be consistently more expensive. The cost associated with increasing from 95 to 98 percent availability is approximately $348 thousand dollars. This accounts for a 28 percent increase in price to achieve a three

percent increase in availability. Conversely, the updated model is able to achieve the same 98 percent availability level at approximately 79 percent of the cost of the original model. The three percent increase for the updated model cost approximately five percent more. There appears to be a pattern forming of which the updated model's forecasting power is not greatly affected by slight changes is the desired availability.

Table 13. Price comparison 13th MEU.

Updated Cost		
Percent of Original	0.96	0.79
Cheaper than Original (Percent)	0.04	0.21
Cost of 3% increase (Original)	$347,715.93	0.28
Cost of 3% increase (Updated)	$58,376.00	0.05

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

3. 15TH MEU

The 15th MEU results show a large difference in the cost associated with both models. Again, we notice that the expected backorder for both models are highly similar with the updated model having a slightly higher expected backorder at 95 percent availability and both models agreeing at 98 percent availability. We once again see the number of each RNSN contained in the class IX block for the respective models is significantly different. At 95 percent availability, only 13.8 percent of the forecasted values agree across both models. At 98 percent availability that similarity increases to

14.9 percent, which is in line with our previous observations. The cost associated with both models are significantly different at both 95 and 98 percent availability. The updated model is 43 and 52 percent cheaper at 95 and 98 percent availability, respectfully. In examining the cost of going from 95 to 98 percent availability we notice that the original model requires a 25 percent increase to achieve the three percent gain. The updated model achieves the same three percent gain with a five percent increase in cost. The cost associated with increasing from 95 to 98 percent availability for the original and updated model is approximately $474 and $56 thousand dollars, respectfully. The pattern remains consistent for the 15th MEU and we once again conclude the updated model's forecasting power is not greatly affected by slight changes is the desired availability.

Table 14. Price comparison 15th MEU.

Updated Cost		
Percent of Original	0.57	0.48
Cheaper than Original (Percent)	0.43	0.52
Cost of 3% increase (Original)	$474,464.94	0.25
Cost of 3% increase (Updated)	$56,156.00	0.05

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

4. 22ND MEU

The 22nd MEU results show a little difference in the cost associated with both models. We notice that the expected backorder for both models are equal. Once again the

number of each RNSN contained in the class IX block for the respective models is significantly different. At 95 percent availability, only 12.1 percent of the forecasted values agree across both models. At 98 percent availability that similarity increases to 12.6 percent. The cost associated with both models are relatively similar at both 95 and 98 percent availability. The updated model is six percent more expensive than the original model at achieving 95 percent availability. At 98 percent availability, the updated model is 12 percent cheaper than the original model. This is the first instance in which achieving the same availability is more costly for the updated model. Examining the cost of going from 95 to 98 percent availability we notice that original model requires a 26 percent increase to achieve the three percent gain. The updated model achieves the same three percent gain with a four percent increase in cost. The cost associated with increasing from 95 to 98 percent availability for the original and updated model is approximately $264 thousand and $44 thousand, respectfully. The pattern remains consistent for the 22nd MEU with the exception of the increased cost of achieving 95 percent availability.

Table 15. Price comparison 22ND MEU.

Updated Cost		
Percent of Original	1.06	0.88
Cheaper than Original (Percent)	-0.06	0.12
Cost of 3% increase (Original)	$263,686.10	0.26
Cost of 3% increase (Updated)	$44,918.00	0.04

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

5. 24TH MEU

The 24th MEU results broke from the pattern seen in the aforementioned results. Although the 22nd MEU results did show that the updated model required greater cost than the original model in achieving 95 percent availability, the 24th MEU is the first time we notice the cost associated with the updated model being significantly more expensive than the original model. As with the other MEUs, the expected backorder values for both models are equal. Once again the number of each RNSN contained in the class IX block for the respective models is significantly different. At 95 percent availability, only 21.5 percent of the forecasted values agree across both models. At 98 percent availability that similarity decreases to 20.7 percent. The cost associated with both models are significantly different at both 95 and 98 percent availability. The updated model is 57 percent more expensive than the original model at achieving 95 percent availability and 31 percent more expensive at achieving 98 percent availability. Examining the cost of going from 95 to 98 percent availability we notice that the original model requires a 24 percent increase to achieve the three percent gain. The updated model achieves the same three percent gain with a three percent increase in cost. The cost associated with increasing from 95 to 98 percent availability for the original and updated model is approximately \$598 and \$134 thousand respectfully. We attempt to understand why the cost associated with the updated model is significantly higher than that of the original model without resolve. One plausible explanation for the increased cost is simply the distribution of goods included in the IX block. Based on the randomness induced in the updated model, we expect to see randomness in the loadout of the IX block.

Table 16. Price comparison 24th MEU.

Updated Cost		
Percent of Original	1.57	1.31
Cheaper than Original (Percent)	-0.57	-0.31
Cost of 3% increase (Original)	$598,455.36	0.24
Cost of 3% increase (Updated)	$133,571.00	0.03

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

6. 26TH MEU

The 26th MEU results reflect the pattern we have seen across the aforementioned results pertaining to the similarity across models. The number of each RNSN contained in the class IX block for the respective models is significantly different with 95 and 98 percent availability possessing 11.4 and 12.8 percent similarity, respectfully. The updated model is 24 percent more expensive than the original model at achieving 95 percent availability and two percent cheaper at achieving 98 percent availability. Examining the cost of going from 95 to 98 percent availability we notice that original model requires a 32 percent increase to achieve the three percent gain while the updated model only requires a five percent increase in cost. The cost associated with increasing from 95 to 98 percent availability for the original and updated model is approximately $363 thousand and $63 thousand, respectfully. We conclude, as consistent with all observations thus far, that the updated model is not greatly affected by slight variability in the desired availability.

Table 17. Price comparison 26th MEU.

Updated Cost		
Percent of Original	1.24	0.98
Cheaper than Original (Percent)	-0.24	0.02
Cost of 3% increase (Original)	$362,891.99	0.32
Cost of 3% increase (Updated)	$63,321.00	0.05

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

7. 31ST MEU

Lastly, we examine the output of both models for the data associated with the 31st MEU. We once again acknowledge the number of each RNSN contained in the class IX block for the respective models is significantly different. At 95 and 98 percent availability, 13.6 percent of the forecasted values agree across both models. The updated model is eight percent more expensive than the original model at achieving 95 percent availability and 10 percent cheaper at achieving 98 percent availability. Examining the cost of going from 95 to 98 percent availability we notice that original model requires a 25 percent increase to achieve the three percent gain while the updated model only requires a four percent increase in cost. The cost associated with the three percent increase in availability is similar to what we saw with the 22nd and 26th MEUs. The cost associated with increasing from 95 to 98 percent availability for the original and updated model is approximately $307 thousand and $53 thousand, respectfully.

Table 18. Price comparison 31st MEU.

Updated Cost		
Percent of Original	1.08	0.90
Cheaper than Original (Percent)	-0.08	0.10
Cost of 3% increase (Original)	$307,520.25	0.25
Cost of 3% increase (Updated)	$52,735.00	0.04

The "Percent of Original" pertains to the cost of providing support at the 95 and 98 availability levels for the updated model respectively. The "Cheaper than Original" simply shows how much cheaper the updated model is in comparison to the original model. It also gives a quick mathematical check; as the sum of the "Percent of Original" and "Cheaper than Original" should always equal one. Lastly, the cost and percent increase of going from 95 to 98 percent availability is given for both the original and updated model.

F. ADDITIONAL ANALYSIS USING R AND BAYESIAN STATISTICS

In order to better understand the variability due to our uncertainty in the lambda values, we decided to further explore the demands and availabilities utilizing a Bayesian approach. That is, we will quantify our uncertainty in lambda through probability distributions rather than using a point estimate. Our calculations in this section are based on a single deployment (hence observation for each part) of the 24th MEU. We chose the 24th MEU because it presented us with the largest dataset for analysis. Although there are 2,903 RNSNs included in the dataset, there were only 106 unique quantities demanded (i.e., lambda's used). Appendix B gives insight into each fixed lambda; however, within the body of this thesis we only examine defined lambdas of interest. We look at the lambdas that pertain to the minimum ($\lambda = 1$), first quartile ($\lambda = 27$), median ($\lambda = 55$), third quartile ($\lambda = 124$), and the maximum ($\lambda = 2040$) demands.

To begin, let us defined what the Bayesian approach provides us. We understand that there is inherent variability in the estimates of λ, therefore, given a single observation (i.e., MEU deployment), the Bayesian approach allows us to construct a probability

distribution on λ and update the distribution if more data becomes available. Based on our aforementioned Poisson assumptions, we chose to utilize Jeffreys reference prior, which states that for a Poisson distribution with no strong prior evidence, we should use $P(\lambda) \propto 1/\lambda$ as our prior probability distribution (Press, 2003, pg. 193). To explore the effects of uncertainty in λ, we accept this prior and utilize it for our analysis. With better data, other priors could be used. Additionally, in Bayesian statistics, if the defined prior is selected from a Gamma distribution (or is proportional to it), and we know our data comes from the Poisson distribution, then our posterior (i.e., the probability distribution on λ after observing the data) is also a Gamma distribution. That is, our prior is a conjugate prior. We use our single observations for the demands for parts to update our priors for our calculations from here forward.

To fully understand the impact of uncertainty on our calculations, it is best to walk through an example that shows how we draw our conclusions on the effect of uncertainty within the lambdas. For simplicity, we start with an observed demand of one (i.e., our initial estimate of lambda), which occurs 1,182 times in the 24th MEU data set. Given that we are using Jeffreys' reference prior, we set alpha, our shape parameter, equal to the demand (one in this case) and beta our scale parameter also to one. We simulate one million occurrences of lambda based on our prior and a single Poisson observation (i.e., the likelihood) at one. The resulting posterior on λ is given in Figure 12 below. We notice that although our initial estimate of lambda is one, when we simulate using a gamma posterior we actually see lambdas within a range of zero to above three. We note that 25 percent of the observations yield a lambda of 1.386 or greater, with a single max observation of lambda of 14.88.

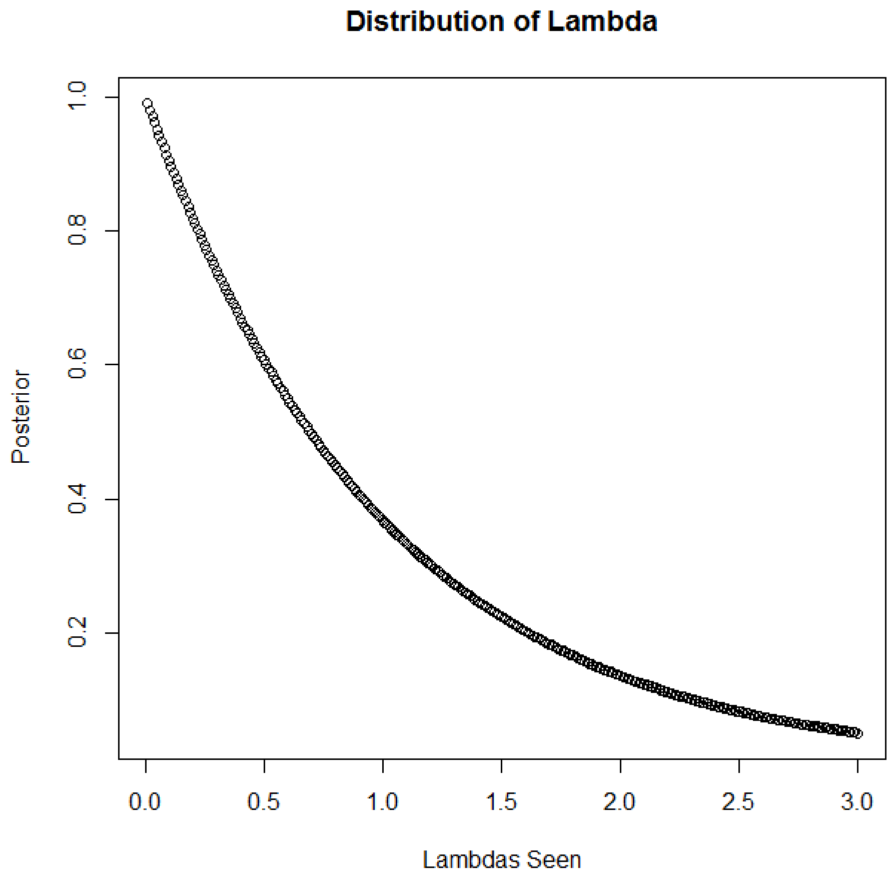


Figure 13. Distribution of one million simulated lambdas given Jeffreys prior and a demand of one.

Of course, we are ultimately interested in the number of parts needed. Thus, by integrating over lambda and determining the Poisson number of parts needed given lambda, we can calculate the distribution of parts ordered with our uncertainty in lambda. We do this by simulation, first generating a random lambda, then, given lambda, generating a random Poisson. We did this one million times. Figure 13 shows a histogram of the simulated observations.

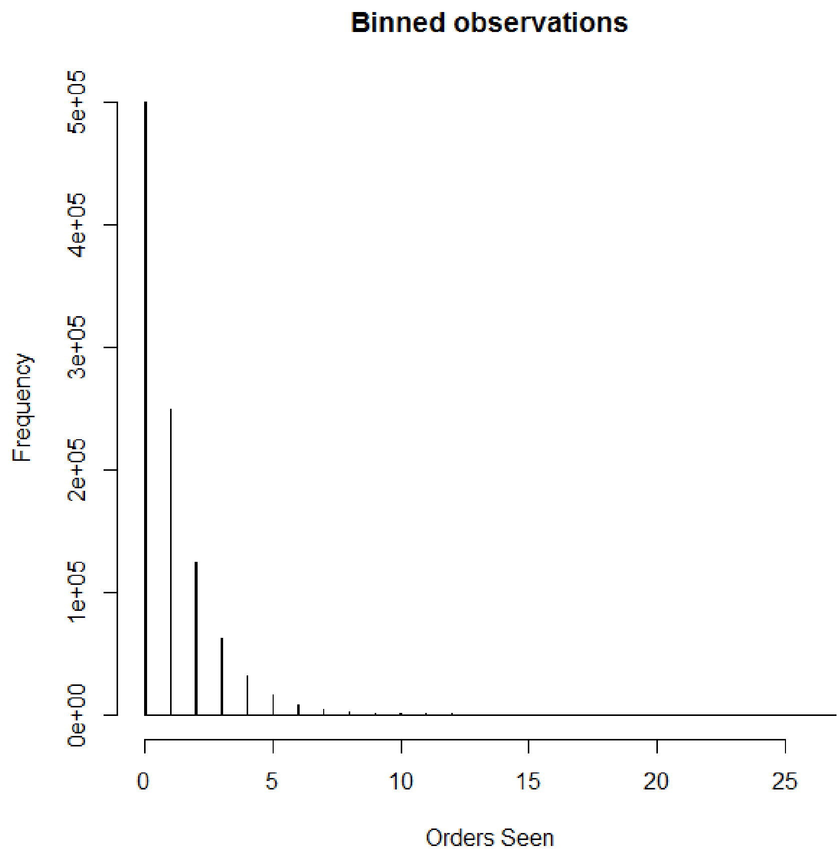


Figure 14. Predictive quantity demanded given a demand of one was observed.

Figure 14 is a replication of the histogram showing the orders based on simulated random lambdas from the Bayesian approach with an overlay of the observation using a single point estimate for lambda (i.e., fixing lambda = one). From the depiction, we see that the point estimate for lambda produces less variability in the number of orders. Thus, if the uncertainty is correct, quantities taken based on a fixed lambda will likely not give the desired availability.

Because of the simulated observations are more variable with a Bayesian approach than when we assumed lambda was fixed, our estimated availabilities will be affected. If lambda was known to be one, then we would need to carry at least three of the specified RNSNs in stock to have at least a 95 percent availability. With our Bayesian approach, we would need to carry at least four to achieve 95 percent availability. If we

carry three parts, the Bayesian approach suggests we would actually have only 93.8 percent availability.

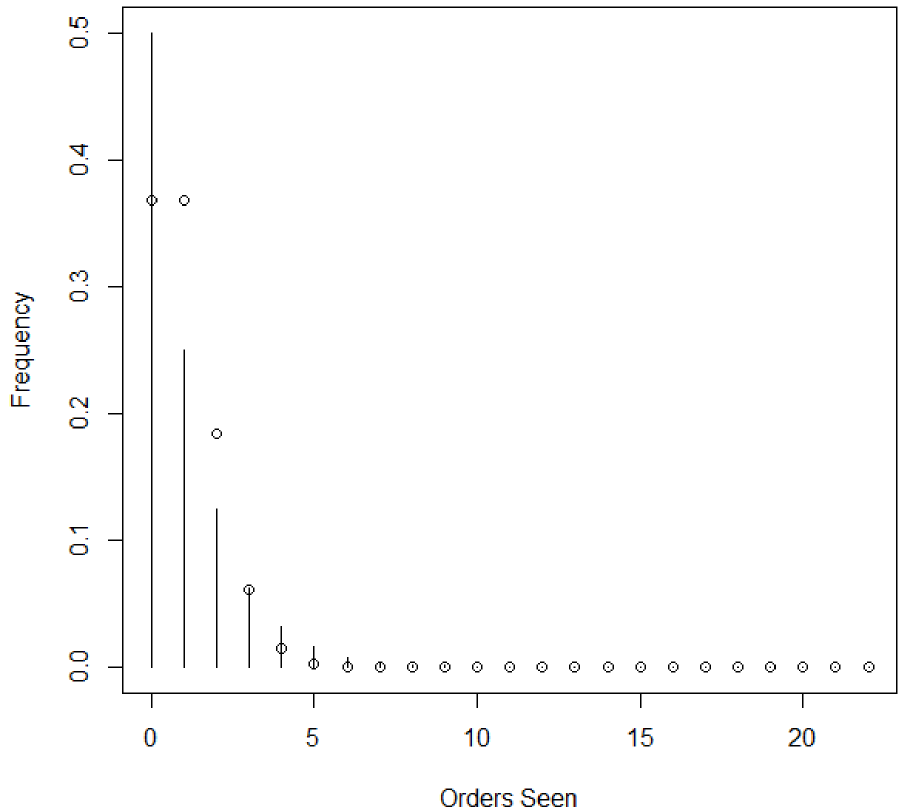
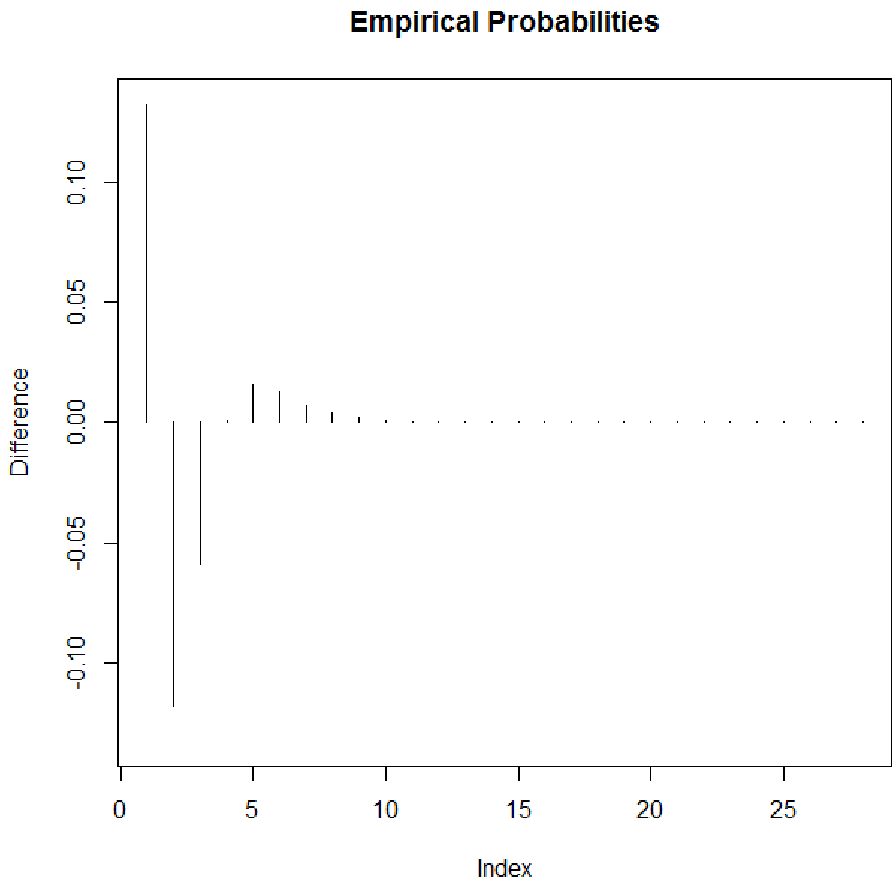


Figure 15. Empirical distributions for the number of parts needed given our Bayesian approach (bars) and assuming a fixed lambda = 1 (circles).

Figure 15 shows the difference in parts used between the Bayesian and fixed lambda approaches. The Bayesian approach makes it more likely to have more extreme parts needed.



The empirical probabilities depicted show that the Bayesian approach results in more variability in the parts needed.

Figure 16. Difference in parts needed between the Bayesian and fixed lambda approaches.

We now look at the largest fixed lambda (i.e., parts ordered) in the 24th MEU, a value of 2,040, and once again simulate to estimate a distribution of possible lambdas given Jeffreys prior. In Figure 16, we notice that with a high parts usage, the posterior density appears approximately normal—as one would expect since the likelihood dominates the prior and the Poisson is roughly normal for large lambda. Additionally, we note that 25 percent of observations are greater than 2,070, with a max observation 2,270.

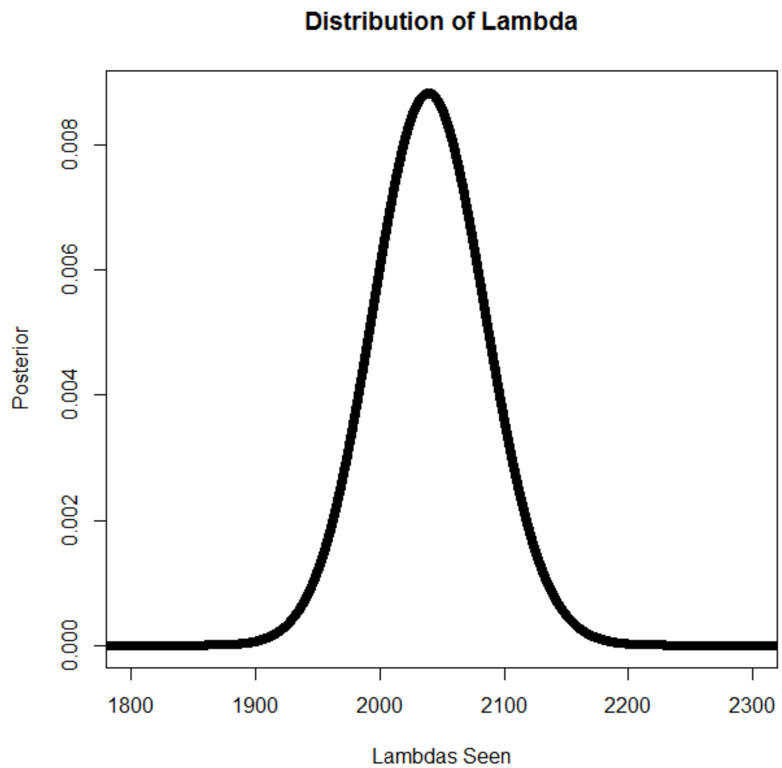


Figure 17. Distribution of one million simulated lambdas given Jeffreys prior and a demand of 2040

We once again look to determine the variability in the outcome of the Poisson orders given the simulated lambdas, based on an original quantity demanded of 2,040. We test this variability for an availability of 95 percent and note the following: given the simulated lambdas we are able to achieve only 88.1 percent availability. Note that if lambda is taken to be 2,040, then to guarantee 95 percent availability we must carry at least 2,115 of the specified RNSNs in stock. The Bayesian approach requires us to take 2,146 to achieve the desired 95 percent availability. Figure 17 shows a histogram of the simulated observations.

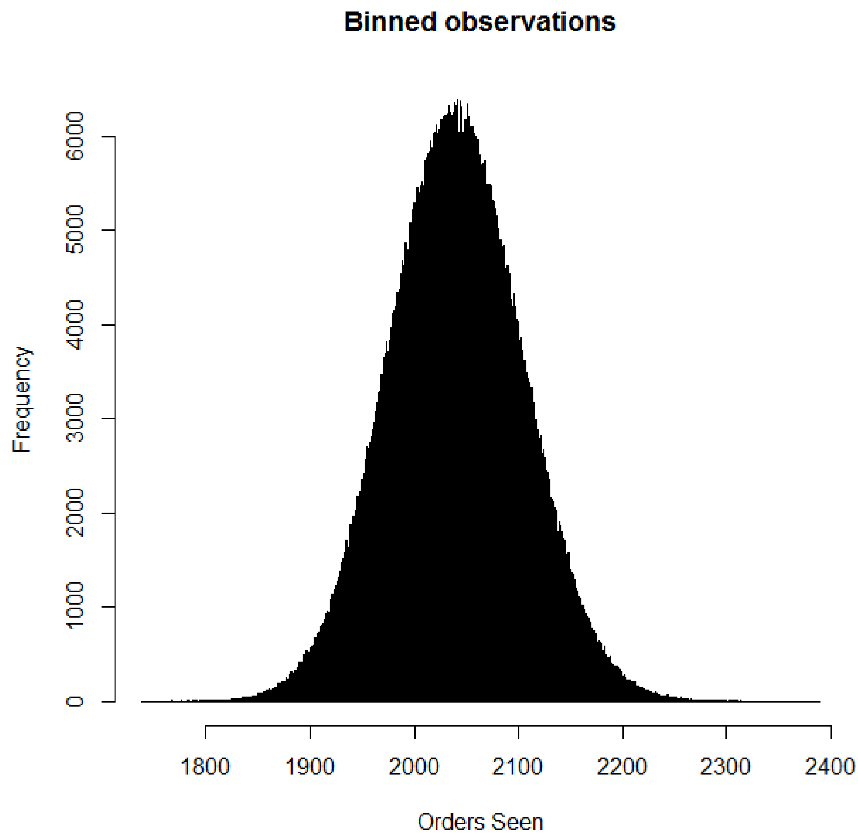
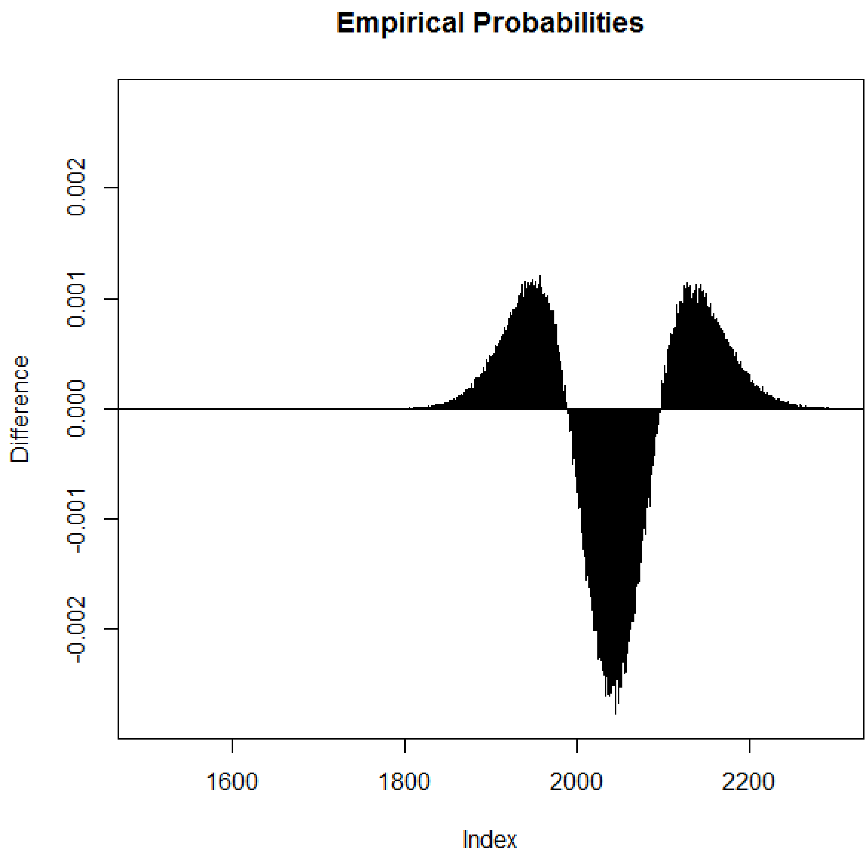


Figure 18. Predictive quantity demanded given a demand of 2,040 was observed.

Figure 18 shows the difference in parts used between the Bayesian and fixed lambda approaches. Once again, the Bayesian approach makes it more likely to have more extreme parts (fewer or more) needed. Thus, to obtain high availabilities, more orders are required than with the fixed lambda approach.



The empirical probabilities depicted show that the Bayesian approach results in significant variability as the estimate of lambda diverges from 2,040.

Figure 19. Difference in parts needed between the Bayesian and fixed lambda approaches.

Figures 19 through Figure 23 depict the difference between the desired availability and actual availability for the minimum and maximum quantity demanded (i.e., estimated fixed lambdas), as well as the lambdas pertaining to the first, second, and third quartiles. From these figures, we see that as the demand increases, the actual availability diverges from the desired availability. This indicates that for low demands and lower operational availability, the actual availability is often higher than the desired availability when we account for uncertainty in lambda. The user is cautioned of this finding, as it can lead to shortages of highly demanded RNSNs while maintaining a surplus of seldom demanded RNSNs. We will further address and discuss this finding in our conclusion and recommendations.

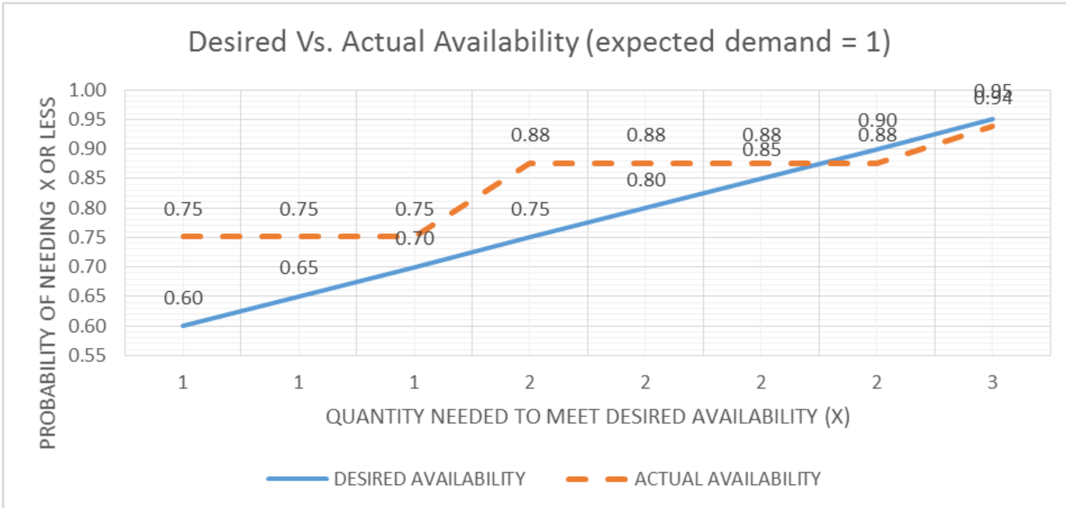


Figure 20. Graphical depiction of the difference between actual and desired availability when expected demand = 1. When the desired availability is above 85 percent, the actual availability is below.

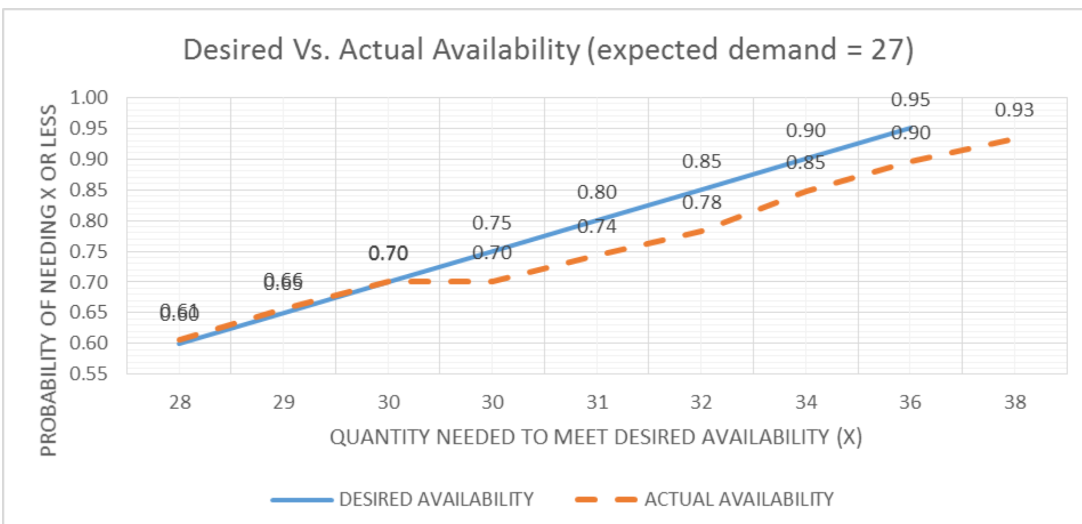


Figure 21. Graphical depiction of the difference between actual and desired availability when expected demand = 27. When the desired availability is above 70 percent, the actual availability is below.

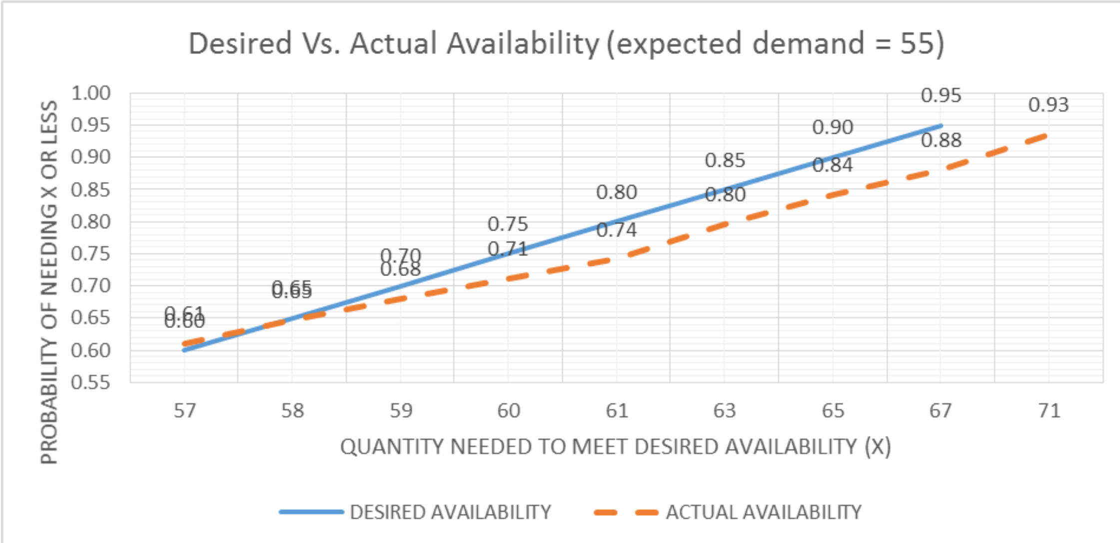


Figure 22. Graphical depiction of the difference between actual and desired availability when expected demand = 55. When the desired availability is above 65 percent, the actual availability is below.

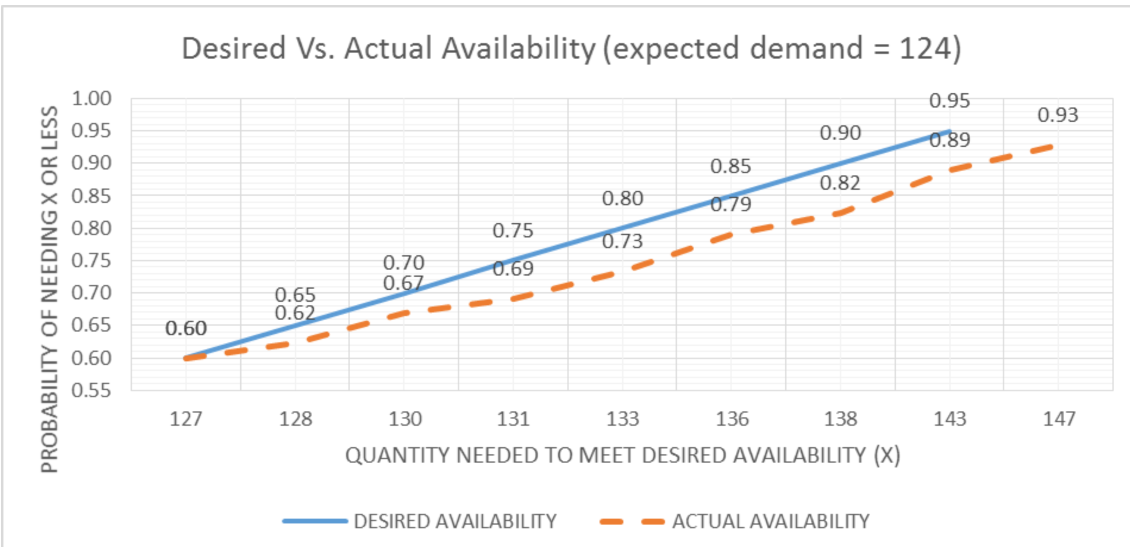


Figure 23. Graphical depiction of the difference between actual and desired availability when expected demand = 124. When the desired availability is above 60 percent, the actual availability is below.

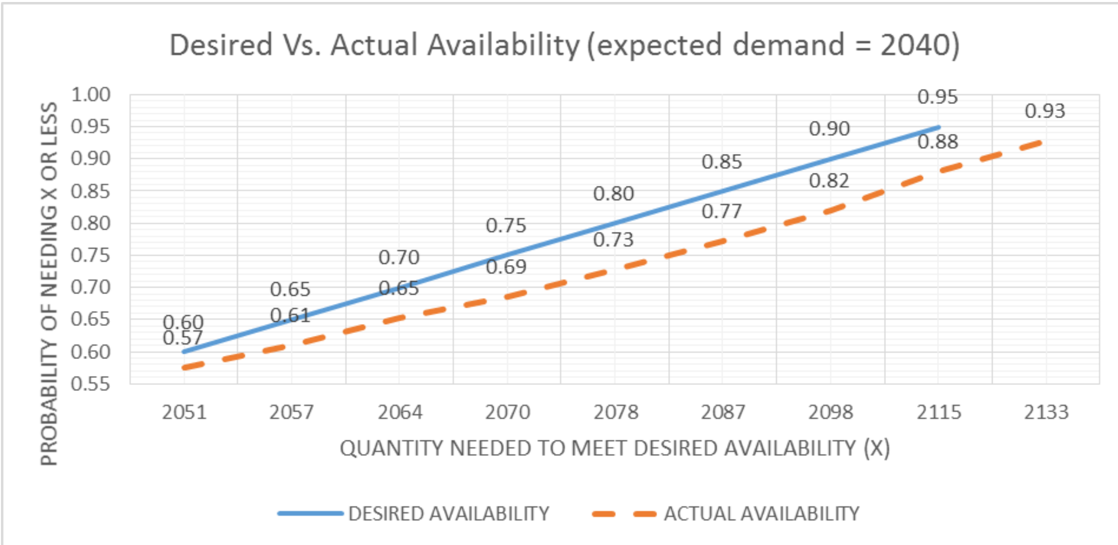


Figure 24. Graphical depiction of the difference between actual and desired availability when expected demand = 2,040. The actual availability is consistently below the desired availability.

Based on our results using the Bayesian approach, we believe that the inclusion of randomness in the lambda parameter in the updated model is a better representation of future occurrences. The uncertainty present in the lambda estimate has significant effect on the results of the Poisson process and we conclude that the updated model gives the user more information in determining the adequate load of the class IX block.

G. CHAPTER SUMMARY

This chapter covered the comparison of both model's outputs. It looked into the uncertainty present in the estimate, as well as how randomness in the lambda parameter can vary the output of the model. We compare the cost of reaching a specified level of availability and how sensitive cost can be in relation to varying the desired availability. The reader should have a good understanding of the inherent variability the original models fails to address and how the updated model gives some insight into planning class IX blocks. Lastly, we introduce a Bayesian approach to estimating lambda and examine how the use of the Bayesian approach can help mitigate the uncertainty present in the estimate of lambda.

V. CONCLUSIONS

A. SUMMARY

This chapter covers how the results from the updated model can provide substantial insight for planners to adequately construct class IX blocks for deploying MEUs. We give recommendations on how the updated model can be used as a guideline for providing suitable support to deployed units.

To begin, emphasis must be placed on the importance of the accuracy and availability of historical data. If the user is able to formulate estimates of lambda that are relatively accurate, then it is left to the user to decide whether the injection of randomness gives any further precision to the forecasting of class IX blocks. To be clear, if the user knows lambda, then we recommend the user use the original model and construct the class IX block based on the model's output. However, in the likely event that the parameter lambda is not known or varies substantially, the user is encouraged to use the updated model and understand the assumptions of the updated models results. Additional data is needed to inform how the uncertainty in lambda is best represented.

B. RESEARCH QUESTIONS ADDRESSED

1. Given an Equipment Density Listing, defined cost constraint, and the desired level of availability, is it possible to accurately forecast the items that are critical to a MEU's class XI block for a defined mission set?

Answer: The updated model allows users to input historical data pertaining to the RNSNs requiring support during a deployment cycle. Utilizing this data, the updated model provides a recommendation on the amount of each RNSN that should be included in the class IX block to maintain the desired availability. The availability level is calculated using Equation (5) as defined in section four. Due to this formulation, the amount included in the class IX block is generally greater or less than the amount that mathematically satisfies the tail probabilities from the Poisson distribution. Including a cost constraint is definitely possible, however, we deduced that including both a cost and availability constraint would likely cause conflict in the program. The most effective way

of injecting a cost constraint would be to remove the availability constraint and simply focus on the level of availability that can be attained on a given budget. This would require optimization and is an ideal expansion of this thesis. Additionally, an optimization model to minimize the storage space needed for the class IX block is also a natural extension of this thesis.

2. The current estimate for the demand rate for National Stock Numbers, which is represented as the arrival rate lambda in a Poisson distribution, lacks robustness. Can we better address the inherent uncertainty of lambda by including variability in the estimate? (secondary question)

Answer: To address the possible variability of lambda, we introduce randomness in lambda by sampling from the Uniform distribution. Understanding that the estimate for lambda is relatively random, we draw our estimates from lambdas in the range starting at half the given lambda to double the given lambda. Doing so allows us to give insight into possible occurrences. Our assumption that the model's forecasting power would benefit from the inclusion of uncertainty is confirmed by the Bayesian approach explored in the thesis. Much more research is needed in how best to model the uncertainty in lambdas.

3. The current standard for modeling number of breakdowns of Marine Corps equipment utilizes a Poisson distribution. Is there any benefit to modeling time between breakdowns with a Weibull distribution? (secondary question)

Answer: The updated model does not address the possibility of fitting the time between failure of Marine Corps equipment to a Weibull distribution. We attempted to address this issue, but realized that the inaccessibility of historical data, specifically time-step data, prevented us from modeling time between failures with the Weibull distribution.

4. Is there a methodological process of prioritizing items that are included in a class IX block? (secondary question)

Answer: The original model addressed prioritization by simply looking at the marginal reduction of adding an RNSN to the class IX block. We adopted this process in the updated model. To further induce prioritization, the user form can be altered to allow the user to input specific RNSNs and the required quantities of those RNSNs in stock. Additionally, the use of optimization in the model as aforementioned would also involve

aspects of prioritization as size and cost constraints become influential in building the class IX block.

5. Is there a possibility of reducing the EDL load without impacting performance? Can the model test and validate a planned load-out of maintenance parts? (secondary question)

Answer: This question is beyond the scope of the research conducted for this thesis. Validating load-outs is left for future work. It is important to note the lack of historical data precluded us from validating our model's results against real world occurrences.

6. Given multiple EDLs for the same mission set, can recommendations be made as to the feasibility of support of each EDL? (secondary question)

Answer: Given an EDL, the updated model will provide the cost associated with supporting each availability level requested. It is left to the user to compare output of the updated model associated with supporting each EDL and draw their own conclusion. An easy metric for comparing EDLs would simply be to examine the cost associated with supporting each EDL. If the EDLs being examined all meet mission requirements, then cost could be a simple method for prioritizing EDLs.

C. KEY INSIGHTS

Without the inclusion of randomness in the lambda estimate, the user inevitably accepts the risk of consistently underestimating the required amount of stock to support a defined availability. The effect of uncertainty is more evident in highly demanded equipment with a tendency for the actual availability to be lower than the desired.

The inclusion of randomness in the updated model appears to allow the user to change the desired availability without great variability in the cost of providing the given availability. We consistently noticed that the original model incurs substantial cost in moving from 95 to 98 percent availability. Table 17 shows the cost associated with attaining all availability levels addressed in the updated model for each MEU. We note that the updated model generally attains the increase from 95 to 98 percent availability at a cost increase of approximately 5 percent while the original models cost exceeds 25 percent. We are unable to ascertain why the updated model is less affected by the

availability constraint. However, because we vary the Poisson parameter, we cause the EBO calculation to change. Varying the EBO will affect the prioritization within the updated model and could explain the varying results of both models.

Table 19. Cost associated with meeting range of availabilities for each MEU.

	COST OF MEETING DESIRED AVAILIBILITY								
MEU	60%	65%	70%	75%	80%	85%	90%	95%	98%
11	$469,455	$489,176	$508,445	$527,299	$546,367	$564,471	$583,634	$610,155	$638,915
13	$601,399	$698,482	$790,214	$877,017	$962,010	$1,042,857	$1,118,176	$1,191,224	$1,249,600
15	$719,540	$763,686	$804,404	$847,777	$906,272	$963,127	$1,019,337	$1,076,895	$1,133,051
22	$805,527	$836,734	$872,681	$919,612	$963,383	$1,004,749	$1,043,791	$1,086,827	$1,131,745
24	$3,056,123	$3,168,643	$3,273,210	$3,391,868	$3,516,784	$3,634,352	$3,745,257	$3,872,526	$4,006,097
26	$759,126	$844,500	$923,550	$1,016,913	$1,120,010	$1,216,811	$1,308,103	$1,394,203	$1,457,524
31	$969,408	$1,017,084	$1,063,546	$1,117,849	$1,168,162	$1,215,770	$1,261,097	$1,311,555	$1,364,290

The end-state of utilizing any forecasting model is to measure the accuracy of the model's forecasting power. The updated model gives results that are vastly different than the original model; however, we are unable to validate and quantify the increase in forecasting power of the updated model. The lack of historical data precludes us from comparing the updated model's results to real life data; thus the accuracy of the updated model is unknown. In comparing the updated model to the original model we have no metric for quantifying the predicative power of either model, thus we rely on cost as a measurement of improvement. We note the need to gather real world data and validate both models.

There exists a void of historical data pertaining to the supply and maintenance readiness of MEU equipment at embarkation. This void greatly limits the ability to conduct research and validate our findings against real-life data. The variability seen in the data used for this thesis is magnified by the inability to compare the quantity demanded of a specific RNSN to the quantity of the RNSN being supported.

The need to forecast future events is ongoing in many fields. This thesis attempts to provide reliable predictions that aid in improving the survivability and readiness of Marine Corps units. At its core, forecasting is based in assumption and always possesses

uncertainty. Continued research is needed into understanding how Marine Corps equipment behaves. This research will be rooted in data that enables the researcher to analyze and extract impactful information that can aid in building models. More resources should be directed toward data collection and analysis as the foundation for the development of more reliable models.

D. RECOMMENDATIONS

- We strongly recommend the exploration of uncertainty when defining a demand rate. From our research, we see how simulating variability in the demand rate significantly effects the projected class IX block forecasted. While the updated model uses a simple factor of two around the lambda estimate being examined, increasing the precision of the lambda estimate and the availability of historical data pertaining to lambda would increase the forecasting power of the model.

- We recommend the gathering and retention of information pertaining to equipment taken on MEUs. Specifically, electronic records must be maintained that clearly define the equipment resident on a MEU's Table of Equipment (TE). Also, electronic records must be maintained that clearly define the RNSNs included in the class IX block taken on ship to support the TE.

E. FOLLOW ON WORK

1. Developing procedure to model Marine Corps data in time-step format.
2. Examining time between breakdowns using a Weibull distribution.
3. Building optimization model that take into account cost of class IX blocks.
4. Building optimization model that focuses on storage space. Specifically, maximizing availability and minimizing space requirements on ship.

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APPENDIX. COMPARISON OF DESIRED VERSUS ACTUAL AVAILABILITY FOR THE 24TH MEU USING BAYESIAN APPROACH

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
1	1	0.60	0.75
1	1	0.65	0.75
1	1	0.70	0.75
1	2	0.75	0.88
1	2	0.80	0.88
1	2	0.85	0.88
1	2	0.90	0.88
1	3	0.95	0.94
1	3	0.98	0.94
2	2	0.60	0.69
2	2	0.65	0.69
2	3	0.70	0.81
2	3	0.75	0.81
2	3	0.80	0.81
2	3	0.85	0.81
2	4	0.90	0.89
2	5	0.95	0.94
2	5	0.98	0.94
3	3	0.60	0.66
3	4	0.65	0.77
3	4	0.70	0.77
3	4	0.75	0.77
3	4	0.80	0.77
3	5	0.85	0.86
3	5	0.90	0.86
3	6	0.95	0.91
3	7	0.98	0.95
4	4	0.60	0.64
4	5	0.65	0.75
4	5	0.70	0.75
4	5	0.75	0.75

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
4	6	0.80	0.83
4	6	0.85	0.83
4	7	0.90	0.89
4	8	0.95	0.93
4	9	0.98	0.95
5	5	0.60	0.62
5	6	0.65	0.73
5	6	0.70	0.73
5	6	0.75	0.73
5	7	0.80	0.81
5	7	0.85	0.81
5	8	0.90	0.87
5	9	0.95	0.91
5	10	0.98	0.94
6	6	0.60	0.61
6	7	0.65	0.71
6	7	0.70	0.71
6	8	0.75	0.79
6	8	0.80	0.79
6	9	0.85	0.85
6	9	0.90	0.85
6	10	0.95	0.90
6	12	0.98	0.95
7	8	0.60	0.70
7	8	0.65	0.70
7	8	0.70	0.70
7	9	0.75	0.77
7	9	0.80	0.77
7	10	0.85	0.83
7	10	0.90	0.83
7	12	0.95	0.92
7	13	0.98	0.94
8	9	0.60	0.68
8	9	0.65	0.68
8	9	0.70	0.68
8	10	0.75	0.76

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
8	10	0.80	0.76
8	11	0.85	0.82
8	12	0.90	0.87
8	13	0.95	0.91
8	14	0.98	0.93
9	10	0.60	0.68
9	10	0.65	0.68
9	10	0.70	0.68
9	11	0.75	0.75
9	11	0.80	0.75
9	12	0.85	0.81
9	13	0.90	0.86
9	14	0.95	0.89
9	16	0.98	0.95
10	11	0.60	0.67
10	11	0.65	0.67
10	12	0.70	0.74
10	12	0.75	0.74
10	13	0.80	0.80
10	13	0.85	0.80
10	14	0.90	0.85
10	15	0.95	0.88
10	17	0.98	0.94
11	12	0.60	0.66
11	12	0.65	0.66
11	13	0.70	0.73
11	13	0.75	0.73
11	14	0.80	0.79
11	14	0.85	0.79
11	15	0.90	0.84
11	17	0.95	0.91
11	18	0.98	0.93
12	13	0.60	0.65
12	13	0.65	0.65
12	14	0.70	0.72
12	14	0.75	0.72

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
12	15	0.80	0.78
12	16	0.85	0.83
12	17	0.90	0.87
12	18	0.95	0.90
12	20	0.98	0.94
13	14	0.60	0.65
13	14	0.65	0.65
13	15	0.70	0.71
13	15	0.75	0.71
13	16	0.80	0.77
13	17	0.85	0.82
13	18	0.90	0.86
13	19	0.95	0.89
13	21	0.98	0.94
14	15	0.60	0.64
14	15	0.65	0.64
14	16	0.70	0.71
14	16	0.75	0.71
14	17	0.80	0.76
14	18	0.85	0.81
14	19	0.90	0.85
14	20	0.95	0.88
14	22	0.98	0.93
15	16	0.60	0.64
15	16	0.65	0.64
15	17	0.70	0.70
15	18	0.75	0.76
15	18	0.80	0.76
15	19	0.85	0.80
15	20	0.90	0.84
15	22	0.95	0.91
15	23	0.98	0.93
16	17	0.60	0.64
16	17	0.65	0.64
16	18	0.70	0.70
16	19	0.75	0.75

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
16	19	0.80	0.75
16	20	0.85	0.80
16	21	0.90	0.84
16	23	0.95	0.90
16	25	0.98	0.94
17	18	0.60	0.63
17	18	0.65	0.63
17	19	0.70	0.69
17	20	0.75	0.74
17	20	0.80	0.74
17	21	0.85	0.79
17	22	0.90	0.83
17	24	0.95	0.89
17	26	0.98	0.94
18	19	0.60	0.63
18	19	0.65	0.63
18	20	0.70	0.69
18	21	0.75	0.74
18	22	0.80	0.79
18	22	0.85	0.79
18	24	0.90	0.86
18	25	0.95	0.89
18	27	0.98	0.93
19	20	0.60	0.62
19	21	0.65	0.68
19	21	0.70	0.68
19	22	0.75	0.73
19	23	0.80	0.78
19	24	0.85	0.82
19	25	0.90	0.85
19	26	0.95	0.88
19	28	0.98	0.93
20	21	0.60	0.62
20	22	0.65	0.68
20	22	0.70	0.68
20	23	0.75	0.73

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
20	24	0.80	0.77
20	25	0.85	0.81
20	26	0.90	0.85
20	28	0.95	0.90
20	30	0.98	0.94
21	22	0.60	0.62
21	23	0.65	0.67
21	23	0.70	0.67
21	24	0.75	0.72
21	25	0.80	0.77
21	26	0.85	0.81
21	27	0.90	0.84
21	29	0.95	0.90
21	31	0.98	0.94
22	23	0.60	0.62
22	24	0.65	0.67
22	24	0.70	0.67
22	25	0.75	0.72
22	26	0.80	0.76
22	27	0.85	0.80
22	28	0.90	0.84
22	30	0.95	0.89
22	32	0.98	0.93
23	24	0.60	0.61
23	25	0.65	0.67
23	25	0.70	0.67
23	26	0.75	0.72
23	27	0.80	0.76
23	28	0.85	0.80
23	29	0.90	0.83
23	31	0.95	0.89
23	33	0.98	0.93
24	25	0.60	0.61
24	26	0.65	0.66
24	26	0.70	0.66
24	27	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
24	28	0.80	0.76
24	29	0.85	0.79
24	30	0.90	0.83
24	32	0.95	0.89
24	35	0.98	0.94
25	26	0.60	0.61
25	27	0.65	0.66
25	27	0.70	0.66
25	28	0.75	0.71
25	29	0.80	0.75
25	30	0.85	0.79
25	32	0.90	0.86
25	33	0.95	0.88
25	36	0.98	0.94
26	27	0.60	0.61
26	28	0.65	0.66
26	29	0.70	0.71
26	29	0.75	0.71
26	30	0.80	0.75
26	31	0.85	0.79
26	33	0.90	0.85
26	35	0.95	0.90
26	37	0.98	0.94
27	28	0.60	0.61
27	29	0.65	0.66
27	30	0.70	0.70
27	30	0.75	0.70
27	31	0.80	0.74
27	32	0.85	0.78
27	34	0.90	0.85
27	36	0.95	0.90
27	38	0.98	0.93
28	29	0.60	0.60
28	30	0.65	0.65
28	31	0.70	0.70
28	31	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
28	32	0.80	0.74
28	33	0.85	0.78
28	35	0.90	0.84
28	37	0.95	0.89
28	39	0.98	0.93
29	30	0.60	0.60
29	31	0.65	0.65
29	32	0.70	0.70
29	33	0.75	0.74
29	33	0.80	0.74
29	35	0.85	0.81
29	36	0.90	0.84
29	38	0.95	0.89
29	41	0.98	0.94
30	31	0.60	0.60
30	32	0.65	0.65
30	33	0.70	0.69
30	34	0.75	0.73
30	35	0.80	0.77
30	36	0.85	0.81
30	37	0.90	0.84
30	39	0.95	0.89
30	42	0.98	0.94
31	32	0.60	0.60
31	33	0.65	0.65
31	34	0.70	0.69
31	35	0.75	0.73
31	36	0.80	0.77
31	37	0.85	0.80
31	38	0.90	0.83
31	40	0.95	0.88
31	43	0.98	0.93
32	33	0.60	0.60
32	34	0.65	0.64
32	35	0.70	0.69
32	36	0.75	0.73

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
32	37	0.80	0.76
32	38	0.85	0.80
32	39	0.90	0.83
32	42	0.95	0.90
32	44	0.98	0.93
34	35	0.60	0.59
34	36	0.65	0.64
34	37	0.70	0.68
34	38	0.75	0.72
34	39	0.80	0.76
34	40	0.85	0.79
34	42	0.90	0.85
34	44	0.95	0.89
34	46	0.98	0.93
35	36	0.60	0.59
35	37	0.65	0.64
35	38	0.70	0.68
35	39	0.75	0.72
35	40	0.80	0.76
35	41	0.85	0.79
35	43	0.90	0.85
35	45	0.95	0.89
35	48	0.98	0.94
36	37	0.60	0.59
36	38	0.65	0.64
36	39	0.70	0.68
36	40	0.75	0.72
36	41	0.80	0.75
36	42	0.85	0.79
36	44	0.90	0.84
36	46	0.95	0.89
36	49	0.98	0.94
37	38	0.60	0.59
37	39	0.65	0.63
37	40	0.70	0.68
37	41	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
37	42	0.80	0.75
37	43	0.85	0.78
37	45	0.90	0.84
37	47	0.95	0.88
37	50	0.98	0.93
38	39	0.60	0.59
38	40	0.65	0.63
38	41	0.70	0.67
38	42	0.75	0.71
38	43	0.80	0.75
38	44	0.85	0.78
38	46	0.90	0.84
38	48	0.95	0.88
38	51	0.98	0.93
39	40	0.60	0.59
39	41	0.65	0.63
39	42	0.70	0.67
39	43	0.75	0.71
39	44	0.80	0.74
39	45	0.85	0.78
39	47	0.90	0.83
39	50	0.95	0.90
39	52	0.98	0.93
40	41	0.60	0.59
40	42	0.65	0.63
40	43	0.70	0.67
40	44	0.75	0.71
40	45	0.80	0.74
40	47	0.85	0.81
40	48	0.90	0.83
40	51	0.95	0.90
40	53	0.98	0.93
41	42	0.60	0.59
41	43	0.65	0.63
41	44	0.70	0.67
41	45	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
41	46	0.80	0.74
41	48	0.85	0.80
41	49	0.90	0.83
41	52	0.95	0.89
41	55	0.98	0.94
42	43	0.60	0.59
42	44	0.65	0.63
42	45	0.70	0.67
42	46	0.75	0.70
42	47	0.80	0.74
42	49	0.85	0.80
42	50	0.90	0.83
42	53	0.95	0.89
42	56	0.98	0.94
43	45	0.60	0.63
43	45	0.65	0.63
43	46	0.70	0.66
43	47	0.75	0.70
43	48	0.80	0.74
43	50	0.85	0.80
43	52	0.90	0.85
43	54	0.95	0.89
43	57	0.98	0.93
44	46	0.60	0.62
44	46	0.65	0.62
44	47	0.70	0.66
44	48	0.75	0.70
44	50	0.80	0.76
44	51	0.85	0.79
44	53	0.90	0.84
44	55	0.95	0.89
44	58	0.98	0.93
46	48	0.60	0.62
46	48	0.65	0.62
46	49	0.70	0.66
46	50	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
46	52	0.80	0.76
46	53	0.85	0.79
46	55	0.90	0.84
46	57	0.95	0.88
46	60	0.98	0.93
47	49	0.60	0.62
47	49	0.65	0.62
47	50	0.70	0.66
47	52	0.75	0.73
47	53	0.80	0.76
47	54	0.85	0.79
47	56	0.90	0.84
47	59	0.95	0.90
47	62	0.98	0.94
48	50	0.60	0.62
48	51	0.65	0.66
48	52	0.70	0.69
48	53	0.75	0.72
48	54	0.80	0.76
48	55	0.85	0.78
48	57	0.90	0.84
48	60	0.95	0.89
48	63	0.98	0.94
49	51	0.60	0.62
49	52	0.65	0.65
49	53	0.70	0.69
49	54	0.75	0.72
49	55	0.80	0.75
49	56	0.85	0.78
49	58	0.90	0.83
49	61	0.95	0.89
49	64	0.98	0.93
50	52	0.60	0.62
50	53	0.65	0.65
50	54	0.70	0.69
50	55	0.75	0.72

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
50	56	0.80	0.75
50	57	0.85	0.78
50	59	0.90	0.83
50	62	0.95	0.89
50	65	0.98	0.93
51	53	0.60	0.62
51	54	0.65	0.65
51	55	0.70	0.69
51	56	0.75	0.72
51	57	0.80	0.75
51	58	0.85	0.78
51	60	0.90	0.83
51	63	0.95	0.89
51	66	0.98	0.93
52	54	0.60	0.61
52	55	0.65	0.65
52	56	0.70	0.68
52	57	0.75	0.72
52	58	0.80	0.75
52	59	0.85	0.78
52	61	0.90	0.83
52	64	0.95	0.89
52	67	0.98	0.93
53	55	0.60	0.61
53	56	0.65	0.65
53	57	0.70	0.68
53	58	0.75	0.72
53	59	0.80	0.75
53	61	0.85	0.80
53	62	0.90	0.82
53	65	0.95	0.88
53	68	0.98	0.93
54	56	0.60	0.61
54	57	0.65	0.65
54	58	0.70	0.68
54	59	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
54	60	0.80	0.74
54	62	0.85	0.80
54	64	0.90	0.84
54	66	0.95	0.88
54	70	0.98	0.94
55	57	0.60	0.61
55	58	0.65	0.65
55	59	0.70	0.68
55	60	0.75	0.71
55	61	0.80	0.74
55	63	0.85	0.80
55	65	0.90	0.84
55	67	0.95	0.88
55	71	0.98	0.93
56	58	0.60	0.61
56	59	0.65	0.65
56	60	0.70	0.68
56	61	0.75	0.71
56	62	0.80	0.74
56	64	0.85	0.79
56	66	0.90	0.84
56	69	0.95	0.89
56	72	0.98	0.93
57	59	0.60	0.61
57	60	0.65	0.64
57	61	0.70	0.68
57	62	0.75	0.71
57	63	0.80	0.74
57	65	0.85	0.79
57	67	0.90	0.84
57	70	0.95	0.89
57	73	0.98	0.93
58	60	0.60	0.61
58	61	0.65	0.64
58	62	0.70	0.68
58	63	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
58	64	0.80	0.74
58	66	0.85	0.79
58	68	0.90	0.84
58	71	0.95	0.89
58	74	0.98	0.93
59	61	0.60	0.61
59	62	0.65	0.64
59	63	0.70	0.68
59	64	0.75	0.71
59	65	0.80	0.74
59	67	0.85	0.79
59	69	0.90	0.83
59	72	0.95	0.89
59	75	0.98	0.93
60	62	0.60	0.61
60	63	0.65	0.64
60	64	0.70	0.67
60	65	0.75	0.70
60	66	0.80	0.73
60	68	0.85	0.79
60	70	0.90	0.83
60	73	0.95	0.89
60	76	0.98	0.93
64	66	0.60	0.60
64	67	0.65	0.64
64	68	0.70	0.67
64	69	0.75	0.70
64	71	0.80	0.75
64	72	0.85	0.78
64	74	0.90	0.82
64	77	0.95	0.88
64	81	0.98	0.93
65	67	0.60	0.60
65	68	0.65	0.64
65	69	0.70	0.67
65	70	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
65	72	0.80	0.75
65	73	0.85	0.78
65	75	0.90	0.82
65	79	0.95	0.89
65	82	0.98	0.93
69	71	0.60	0.60
69	72	0.65	0.63
69	73	0.70	0.66
69	75	0.75	0.72
69	76	0.80	0.75
69	78	0.85	0.80
69	80	0.90	0.84
69	83	0.95	0.89
69	87	0.98	0.94
70	72	0.60	0.60
70	73	0.65	0.63
70	74	0.70	0.66
70	76	0.75	0.72
70	77	0.80	0.75
70	79	0.85	0.79
70	81	0.90	0.84
70	84	0.95	0.89
70	88	0.98	0.94
75	77	0.60	0.60
75	78	0.65	0.63
75	79	0.70	0.66
75	81	0.75	0.71
75	82	0.80	0.74
75	84	0.85	0.79
75	86	0.90	0.83
75	90	0.95	0.89
75	93	0.98	0.93
80	82	0.60	0.59
80	83	0.65	0.62
80	85	0.70	0.68
80	86	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
80	87	0.80	0.73
80	89	0.85	0.78
80	92	0.90	0.84
80	95	0.95	0.89
80	99	0.98	0.93
83	85	0.60	0.59
83	86	0.65	0.62
83	88	0.70	0.68
83	89	0.75	0.70
83	91	0.80	0.75
83	92	0.85	0.77
83	95	0.90	0.84
83	98	0.95	0.88
83	102	0.98	0.93
84	86	0.60	0.59
84	87	0.65	0.62
84	89	0.70	0.68
84	90	0.75	0.70
84	92	0.80	0.75
84	94	0.85	0.79
84	96	0.90	0.83
84	99	0.95	0.88
84	103	0.98	0.93
85	87	0.60	0.59
85	88	0.65	0.62
85	90	0.70	0.68
85	91	0.75	0.70
85	93	0.80	0.75
85	95	0.85	0.79
85	97	0.90	0.83
85	100	0.95	0.88
85	104	0.98	0.93
87	89	0.60	0.59
87	90	0.65	0.62
87	92	0.70	0.67
87	93	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
87	95	0.80	0.75
87	97	0.85	0.79
87	99	0.90	0.83
87	103	0.95	0.89
87	107	0.98	0.93
90	92	0.60	0.59
90	94	0.65	0.64
90	95	0.70	0.67
90	96	0.75	0.70
90	98	0.80	0.74
90	100	0.85	0.79
90	102	0.90	0.83
90	106	0.95	0.89
90	110	0.98	0.93
92	94	0.60	0.59
92	96	0.65	0.64
92	97	0.70	0.67
92	98	0.75	0.69
92	100	0.80	0.74
92	102	0.85	0.79
92	104	0.90	0.82
92	108	0.95	0.89
92	112	0.98	0.93
96	98	0.60	0.58
96	100	0.65	0.64
96	101	0.70	0.67
96	103	0.75	0.71
96	104	0.80	0.74
96	106	0.85	0.78
96	109	0.90	0.84
96	112	0.95	0.88
96	117	0.98	0.93
100	102	0.60	0.59
100	104	0.65	0.64
100	105	0.70	0.66
100	107	0.75	0.71

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
100	108	0.80	0.73
100	110	0.85	0.78
100	113	0.90	0.83
100	117	0.95	0.89
100	121	0.98	0.93
102	104	0.60	0.58
102	106	0.65	0.64
102	107	0.70	0.66
102	109	0.75	0.71
102	110	0.80	0.73
102	112	0.85	0.77
102	115	0.90	0.83
102	119	0.95	0.89
102	123	0.98	0.93
103	105	0.60	0.58
103	107	0.65	0.63
103	108	0.70	0.66
103	110	0.75	0.71
103	111	0.80	0.73
103	114	0.85	0.79
103	116	0.90	0.83
103	120	0.95	0.89
103	124	0.98	0.93
108	110	0.60	0.58
108	112	0.65	0.63
108	113	0.70	0.66
108	115	0.75	0.70
108	117	0.80	0.75
108	119	0.85	0.79
108	121	0.90	0.82
108	125	0.95	0.88
108	130	0.98	0.93
110	113	0.60	0.60
110	114	0.65	0.63
110	115	0.70	0.66
110	117	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
110	119	0.80	0.75
110	121	0.85	0.78
110	124	0.90	0.84
110	128	0.95	0.89
110	132	0.98	0.93
113	116	0.60	0.60
113	117	0.65	0.63
113	118	0.70	0.65
113	120	0.75	0.70
113	122	0.80	0.74
113	124	0.85	0.78
113	127	0.90	0.83
113	131	0.95	0.89
113	135	0.98	0.93
114	117	0.60	0.60
114	118	0.65	0.63
114	119	0.70	0.65
114	121	0.75	0.70
114	123	0.80	0.74
114	125	0.85	0.78
114	128	0.90	0.83
114	132	0.95	0.89
114	136	0.98	0.93
117	120	0.60	0.60
117	121	0.65	0.63
117	123	0.70	0.67
117	124	0.75	0.70
117	126	0.80	0.74
117	128	0.85	0.78
117	131	0.90	0.83
117	135	0.95	0.88
117	140	0.98	0.93
124	127	0.60	0.60
124	128	0.65	0.62
124	130	0.70	0.67
124	131	0.75	0.69

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
124	133	0.80	0.73
124	136	0.85	0.79
124	138	0.90	0.82
124	143	0.95	0.89
124	147	0.98	0.93
135	138	0.60	0.60
135	139	0.65	0.62
135	141	0.70	0.66
135	143	0.75	0.71
135	145	0.80	0.75
135	147	0.85	0.78
135	150	0.90	0.83
135	154	0.95	0.88
135	159	0.98	0.93
136	139	0.60	0.59
136	140	0.65	0.62
136	142	0.70	0.66
136	144	0.75	0.70
136	146	0.80	0.74
136	148	0.85	0.78
136	151	0.90	0.83
136	155	0.95	0.88
136	160	0.98	0.93
138	141	0.60	0.59
138	142	0.65	0.62
138	144	0.70	0.66
138	146	0.75	0.70
138	148	0.80	0.74
138	150	0.85	0.78
138	153	0.90	0.83
138	158	0.95	0.89
138	163	0.98	0.93
139	142	0.60	0.59
139	143	0.65	0.62
139	145	0.70	0.66
139	147	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
139	149	0.80	0.74
139	151	0.85	0.78
139	154	0.90	0.83
139	159	0.95	0.89
139	164	0.98	0.93
148	151	0.60	0.59
148	153	0.65	0.64
148	154	0.70	0.66
148	156	0.75	0.70
148	158	0.80	0.74
148	161	0.85	0.79
148	164	0.90	0.83
148	168	0.95	0.88
148	174	0.98	0.93
154	157	0.60	0.59
154	159	0.65	0.63
154	160	0.70	0.65
154	162	0.75	0.69
154	164	0.80	0.73
154	167	0.85	0.78
154	170	0.90	0.83
154	175	0.95	0.89
154	180	0.98	0.93
158	161	0.60	0.59
158	163	0.65	0.63
158	164	0.70	0.65
158	166	0.75	0.69
158	169	0.80	0.75
158	171	0.85	0.78
158	174	0.90	0.82
158	179	0.95	0.89
158	184	0.98	0.93
160	163	0.60	0.59
160	165	0.65	0.63
160	167	0.70	0.67
160	168	0.75	0.69

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
160	171	0.80	0.75
160	173	0.85	0.78
160	176	0.90	0.82
160	181	0.95	0.88
160	187	0.98	0.93
166	169	0.60	0.59
166	171	0.65	0.63
166	173	0.70	0.67
166	175	0.75	0.71
166	177	0.80	0.74
166	179	0.85	0.77
166	183	0.90	0.83
166	187	0.95	0.88
166	193	0.98	0.93
172	175	0.60	0.58
172	177	0.65	0.63
172	179	0.70	0.66
172	181	0.75	0.70
172	183	0.80	0.74
172	186	0.85	0.79
172	189	0.90	0.83
172	194	0.95	0.89
172	199	0.98	0.93
189	192	0.60	0.58
189	194	0.65	0.62
189	196	0.70	0.66
189	198	0.75	0.69
189	201	0.80	0.75
189	203	0.85	0.78
189	207	0.90	0.83
189	212	0.95	0.88
189	218	0.98	0.93
200	203	0.60	0.58
200	205	0.65	0.62
200	207	0.70	0.65
200	209	0.75	0.69

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
200	212	0.80	0.74
200	215	0.85	0.78
200	218	0.90	0.82
200	224	0.95	0.89
200	230	0.98	0.93
201	204	0.60	0.58
201	206	0.65	0.62
201	208	0.70	0.65
201	210	0.75	0.69
201	213	0.80	0.74
201	216	0.85	0.78
201	219	0.90	0.82
201	225	0.95	0.89
201	231	0.98	0.93
203	206	0.60	0.58
203	208	0.65	0.62
203	210	0.70	0.65
203	213	0.75	0.71
203	215	0.80	0.74
203	218	0.85	0.78
203	221	0.90	0.82
203	227	0.95	0.89
203	233	0.98	0.93
204	207	0.60	0.58
204	209	0.65	0.62
204	211	0.70	0.65
204	214	0.75	0.71
204	216	0.80	0.74
204	219	0.85	0.78
204	222	0.90	0.82
204	228	0.95	0.89
204	234	0.98	0.93
214	218	0.60	0.59
214	219	0.65	0.61
214	222	0.70	0.67
214	224	0.75	0.70

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
214	226	0.80	0.73
214	229	0.85	0.78
214	233	0.90	0.83
214	238	0.95	0.88
214	245	0.98	0.93
227	231	0.60	0.59
227	233	0.65	0.63
227	235	0.70	0.66
227	237	0.75	0.70
227	240	0.80	0.74
227	243	0.85	0.78
227	246	0.90	0.82
227	252	0.95	0.88
227	258	0.98	0.93
300	304	0.60	0.58
300	307	0.65	0.63
300	309	0.70	0.66
300	312	0.75	0.70
300	315	0.80	0.74
300	318	0.85	0.78
300	322	0.90	0.82
300	329	0.95	0.88
300	336	0.98	0.93
386	391	0.60	0.58
386	393	0.65	0.61
386	396	0.70	0.65
386	399	0.75	0.69
386	402	0.80	0.73
386	406	0.85	0.77
386	411	0.90	0.82
386	419	0.95	0.88
386	427	0.98	0.93
405	410	0.60	0.58
405	413	0.65	0.62
405	415	0.70	0.65
405	418	0.75	0.69

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
405	422	0.80	0.73
405	426	0.85	0.78
405	431	0.90	0.82
405	438	0.95	0.88
405	447	0.98	0.93
422	427	0.60	0.58
422	430	0.65	0.62
422	433	0.70	0.66
422	436	0.75	0.70
422	439	0.80	0.73
422	443	0.85	0.77
422	448	0.90	0.82
422	456	0.95	0.88
422	465	0.98	0.93
512	518	0.60	0.59
512	521	0.65	0.62
512	524	0.70	0.66
512	527	0.75	0.69
512	531	0.80	0.73
512	535	0.85	0.77
512	541	0.90	0.82
512	549	0.95	0.88
512	559	0.98	0.93
520	526	0.60	0.59
520	529	0.65	0.62
520	532	0.70	0.66
520	535	0.75	0.69
520	539	0.80	0.73
520	544	0.85	0.78
520	549	0.90	0.82
520	558	0.95	0.88
520	567	0.98	0.93
653	659	0.60	0.58
653	663	0.65	0.62
653	666	0.70	0.65
653	670	0.75	0.69

LAMBDA SEEN ON THE 24THMEU	EXACT QUANTITY NEEDED TO MAINTAIN DESIRED AO	DESIRED AVAILABILITY	ACTUAL AVAILABILITY
653	674	0.80	0.73
653	679	0.85	0.77
653	686	0.90	0.82
653	695	0.95	0.88
653	706	0.98	0.93
1300	1309	0.60	0.58
1300	1314	0.65	0.62
1300	1319	0.70	0.65
1300	1324	0.75	0.69
1300	1330	0.80	0.73
1300	1337	0.85	0.77
1300	1346	0.90	0.82
1300	1360	0.95	0.88
1300	1375	0.98	0.93
2040	2051	0.60	0.57
2040	2057	0.65	0.61
2040	2064	0.70	0.65
2040	2070	0.75	0.69
2040	2078	0.80	0.73
2040	2087	0.85	0.77
2040	2098	0.90	0.82
2040	2115	0.95	0.88
2040	2133	0.98	0.93

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